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II

CLIMATIC CYCLES AND TREE-GROWTH

VOLUME II

A STUDY OF THE ANNUAL RINGS OF TREES IN RELATION TO CLIMATE AND SOLAR ACTIVITY

BY

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With nine plates and nineteen text figures

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I. INTRODUCTION

In a dry region the dominating physical factor in tree-growth is moisture. It is impossible for anyone to realize how vital it is without actual residence—a mere trip through a desert is far from sufficient, for it lacks the time element. One must live in it by night and by day, in rainy and in dry season, in drought and in wet cycle. One must see the burning sun, the sparse shrubs, the clear skies, the striking colors of earth, rock, and sky, without the green of vegetation, followed by the strong primitive atmospheric colors when the sun is just below the horizon; he must see the round green cedars and the ever watchful isolated pines of higher elevations; he must see green valley bottoms and herds escaping from sight through deep range grass at one time, and later on he must travel through cactus wastes and dead cattle lying beside dried-up water-holes. And all this must be lived with to afford full realization. The visitor from wet climates does not sense it all for the first year or two, for day by day he unconsciously expects a change, as has always happened in his previous experience. But after a year or more he is able to realize the excessive value of moisture and even to recognize the evidence of climatic changes.

This was the approach in the present study of climate and trees. Many investigators have come to the study of growth variations from other viewpoints. For example, a large number think of them in terms of pests, for economic necessity has demanded their study, especially in wet climates, where timber is abundant and they are nature's agents for maintaining an equilibrium. It is true that the relation of the abundance of animal life, even pests, to climatic conditions is receiving more and more consideration, but the supreme rôle of rain in a dry climate needs to be a matter of constant experience in order to bring appreciation of the relation of tree-growth to moisture in the Southwest.

AFFILIATIONS

At the outset this work was recognized as on the borderland between astronomy, meteorology, and botany, and as needing help and information from each with some expectation of ultimate return. To some degree this return is realized in the present volume, which gives for the astronomers some evidence of a real history of solar

changes for many centuries, for the meteorologists certain drought conditions and climatic changes over a similar length of time, and for the botanists an opportunity for learning how vegetation reacts to certain phases of its environment. In addition, various problems of dating, such as the chronology of the prehistoric ruins of the Southwest, have received a new approach, but solar and climatic cycles with an ultimate view to seasonal prediction have continued the central theme.

Prediction possibility has been one of the great incentives to recent work upon tree-rings. There seem to be two approaches to long-range forecasting. One is by direct tracing of the physical causes and the other is by learning the history of past changes and working out empirical methods. Each needs the other; so the climatic history written in trees is doubly useful, for it may of itself give means of foretelling the future, if such can be found, and, on the other hand, if the physical causation is traced first, the derived line of causes must agree with and explain this known history in trees. Thus prediction will gain at once greater reliability. The last chapter in the book deals with the various climatic cycles found in trees.

The effort to find a basis of seasonal prediction is the modern phase of an age-old problem. In our day of newspapers, calendars, and clocks it is hard to realize that at the beginning of prehistoric agriculture farmers knew little of the time of day or the time of year except as signs in the heavens told it to the rare man who had learned the language of the sky. We are now in the same stage of ignorance regarding yet longer cycles and hope to find our time in relation to them so that we may know better when and what to produce each season for modern needs.

DEVELOPMENT

With a conviction of the climatic value of tree-ring studies, one can see two general lines of development, roughly described as extension in space about the world at the present time and extension in time to past eras. The former has economic and scientific value, because, in this way, climatic variations in different hemispheres, continents, and latitudes may, within limits, be studied, in spite of absence of formal instrumental records; so also the effects of mountain ranges, continental contours, different orientation of exposure, and the reaction of vegetation under different conditions. A beginning is made in this volume along these lines. A set of yellow pine ring records has been obtained from the Western States, and especially the Southwest, by which a large area can be reviewed and a first estimate made of effects such as those just mentioned.

Similar information regarding past climates is contained in fossil trees. Without knowing exact dates, we can learn something about

the climatic and solar changes in various geologic periods, Tertiary, Pleistocene, Prehistoric, and Protohistoric. The methods and instruments developed in this research give us an improved approach to various types of geologic material besides fossil woods. Chief among these are the clay layers of de Geer and Antevs, dealing with the retreat of the ice-sheet, the andesite laminations of Udden in Texas, and the stalagmite deposits of Allison. This geologic material, with much more that will come to light, will not be included in the present volume, but will be reserved for future discussion.

One can see that in all this we are measuring the lapse of time by means of a slow-geared clock within the trees. For this study the name "dendro-chronology" has been suggested, or "tree-time." This expression covers all the dating and historic problems referred to in the following chapters, as well as the study of cyclic variations and the distribution of climatic conditions.

COÖPERATION

But with this development there is added need of information from other sciences. The relationship of solar activity to weather is a part of a rather specialized department of astronomical science called astrophysics. There is help which one needs from that science, but which one can not yet obtain; for example, the hourly variations in the solar constant. One would like to know whether the relative rate of rotation and the relative temperatures of different solar latitudes vary in terms of the 11-year sunspot period. These questions have to do with some of the theories proposed in attempting to explain the sunspot periodicity. We do not know the cause of the 11-year sunspot period. Here, then, is work for the astronomers. Climate is a part of meteorology, and the data which we use are obtained largely from the Weather Bureau. The observing stations are usually located in cities, and therefore we can not get data from proper places in the Sierra Nevada Mountains of California, where the giant sequoia lives. Considering that this big tree gives us the longest uninterrupted series of climatic effects whose dates are accurately known, which we have so far obtained from any source, it must be greatly regretted that we have no long modern records by which to interpret the writing in those wonderful trees. So far as I am aware, only one attempt is now being made to get complete records for the future.*

From the botanists and ecologists we need to know the exact time of ring formation, the ability of the tree to conserve moisture against the day of drought, the soil-moisture gradients at different months, the different action of the tree in putting on a different color of wood in the spring and autumn growth.

In dating problems, this study has developed another important

*Col. John R. White, in Sequoia National Park.

contact. The rings in the beams of ancient ruins tell a story of the time of building, both as to its climate and the number of years involved and the order of building, perhaps ultimately the date of building. All this is anthropology, and much data from the archæologists will help in identifying the rings in beams and supply valuable climatic records of long-past times.

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PREVIOUS WORK

The first publication by the author was in 1909, in the Monthly Weather Review. This was followed by other articles until the whole was summarized in 1919 in a volume with the same title as the present one and published under the same auspices. At that time identification and measurement had been made of about 75,000 rings in some 230 different trees from the States of Oregon, California, Arizona, Colorado, and Vermont, as well as from England, Norway, Sweden, Germany, and Bohemia (near Pilsen). That volume dealt with studies upon the yellow pine about Flagstaff, Arizona, climatic conditions there, the yearly identity of rings, cross-identification, time of year of ring formation, number of trees necessary, the actual collection of yellow and Scotch pine and sequoia samples, methods of curve production, correlation with rainfall and with solar activity, and cycles and methods of determining them. The present book opens with the development of technique in collecting and treating specimens.

II. TREE SELECTION

Rings of trees have told many stories of the past. By their mere enumeration the historian has built up our realization of great events in human progress; by more careful counting the forester has discovered the dates of ancient destructive fires; by changes in the rings ecologists have determined historic changes in lakes and rivers and settled questions of legal ownership. The present study of climate and solar activity uses the accurate dating and width of rings over wide geographical areas and into times long past for several purposes, but chiefly to derive an understanding of that immensely complex process by which climatic forces reach the earth and distribute themselves about it. This, it is hoped, will eventually lead to safe long-range prediction of climatic conditions. In the present approach to the subject, the recent development of technique is given first, and this chapter deals with the selection of trees for climatic study.

SPECIES

Pines—The western yellow pine is perhaps the best tree for climatic studies, on account of its precision and length of record and its wide distribution. It is normally a dry-climate tree and does well in a sandy soil, for its thick bark prevents evaporation from the trunk and thus enables it to live when other trees could not survive. Thus it endures relatively trying conditions and has little competing vegetation, so that the Arizona forest is said to be the largest "pure" stand in the country. It can be injured by too much moisture in the soil, and draining then improves it. Its age is very favorable, reaching over 500 years. It is commonly free from burns and defects and its rings are very readable. The immense area over which the yellow pine grows adds to its value in this study, as its use avoids the complexities arising from the use of different species. For all these reasons it is considered the standard tree.

The Scotch pine of north Europe is very similar, but not usually so large. However, this is because the European regions have been cut over so much that very old trees are rare. The white pine in the Appalachian Mountains cross-identifies very well. The pines in eastern Massachusetts are less satisfactory, probably because the region is too much cultivated. Very old hemlocks in the Green Mountains of Vermont have rings extraordinarily like those of the western yellow pine and almost as perfect in cross-identification.

White pines in the Yellowstone are good, and a few white or limber pines near Flagstaff give records that are readable, but the locations in which they grow are so rugged and variable that a complete test has not been made of them. The foxtail pine at high altitudes sometimes

reaches a great age, but its rings are more complacent than those of the yellow pine. It reminds one of a cedar.

Sugar pine—Sugar pines are fine, large trees, but the rings are large and the age is often disappointing. The distribution is much more limited than the yellow pine; from which one assumes that it will not stand so great a variation of moisture. Ring records of this species on Mount Wilson resemble very closely similar records from the adjacent yellow pines. Like the Douglas fir, it is a good occasional substitute for the yellow pine, but is far from its equal as a standard tree in southwestern climatic study. Substitute trees have given so many cases of satisfactory records that one feels it always worth while to use some other tree than the yellow pine where such standard trees are scarce.

Douglas fir (spruce)—In the Arizona Mountains this tree borders the pine belt on the upper, which is the colder and more rainy side. It mixes with the yellow pine to a small degree and is the first choice as substitute when the pines are infrequent in any site. The trees, even if bigger, are apt to be younger, with larger growth each year. The rings are usually well marked and free from errors and cross-identify perfectly with neighboring yellow pines. It is somewhat apt to exaggerate climatic influences.

Other spruces—The Sitka spruce of our northwest coast (tested in Oregon and Washington) has heavy, emphatic rings of a complacent sort and so far has not seemed a desirable tree. It grows to exceedingly large size. A fine specimen some 9 feet through, in the American Museum in New York, gives a good idea of what it is. This particular specimen exhibits some very unusual spiral gross-rings whose origin it would be interesting to determine. This spruce grows at low, well-watered levels near the coast, and so its value as a climatic record is probably low.

The Engelmann spruce of high altitudes is even less valuable in this respect. It grows at elevations over 8,000 feet at Pike's Peak and at 10,000 on the San Francisco Peaks (Arizona). Its rings have very little variation and do not cross-identify with neighboring pines and Douglas firs. Owing to these characteristics it has practically no value as a climatic record.

The European spruce, *Picea excelsa*, is much better. While more complacent than the very satisfactory Scotch pine there, it does show good ring variations which can be dated and in one or two special cases give a remarkable record of solar variations. Such is No. S 14 from southern Sweden, whose photograph is given here (see Plate 9) because it did not come in time for insertion in the first volume. Its curve of growth was given in Volume I, page 75, figure 22. It is therefore unusual and interesting.

Sequoias—In this review of western trees the mountain sequoia (*Sequoia gigantea*) easily takes a leading part in company with the yellow pine, for besides its great age it has a fundamental feature of greatest importance, namely, cross-identification over large areas. In this character we recognize climatic influences. The ring-growth in the big sequoia is not so sensitive as in the yellow pine, and perhaps any individual tree is a little less certain to identify with its neighbors, but yet cross-identification is very sure in that species and extends through all the mountain sequoia groves from Calaveras on the north to Springville on the south, 200 miles. The southern groves, which yield the best results, give a record obviously similar to that of the yellow pines in neighboring locations. It is true that the sequoia needs a large moisture supply, probably more than it usually gets, but its location is so high on the mountains that the winters completely interrupt the growth and therefore make the record in the rings very reliable as to its annual character. The great age of this tree gives it a second fundamental value. It is astonishing, for example, to find over considerable areas similar identifiable rings near 1,000 B. C. Further study upon the sequoia will improve our knowledge of the normal growth-curve in relation to age, so that we can by extrapolation tell with some precision what the climate was 3,000 years ago. This requires many corrections, such as that for flare of the base, for slanting rings, and for the indentations of the trunk which come from root relationship. All these factors differ so much in individual trees that it would seem profitable to study each tree specially, and in recent collecting I have made notes about every stump and have distributed the ages more carefully. (See Huntington, 1914.)

Coast redwood—The coast redwood (*Sequoia sempervirens*) has been a disappointment, because after most careful tests it has failed entirely to show cross-identification. This is undoubtedly due to its climatic environment. Various attempts to make use of this tree are described below (Chapter VI).

Junipers—The junipers and cedars are important in this review, because in Arizona mountains they border the yellow pines on the lower and therefore the warmer and drier side. As one ascends from the desert to the forest areas, the first dark-green rounded trees are the junipers of several different species. The growth of the juniper is slow and the rings are often attractive, but for actual use disappointing. One species branches at the ground and so seems impossible; another has deep vertical indentations in the trunk, with erratic rings. The growth can rarely be traced from lobe to lobe of a cross-section. Often the rings condense so that identity is hopelessly lost.* The more promising species is the pachyphlœa or alligator-bark juniper, which

* Some successful work has recently been done on the junipers.

grows close to or in the pine belt. Its rings are apt to be complacent, with considerable difference in mean size due to locality. From the average rate of growth of junipers measured near Cibecue, 500 to 700 years would seem to be the usual maximum age of this tree.

This species has one idiosyncrasy which often rules out an attractive tree. A vertical half may die and the other half live. This may happen to the trunk and follow up some of the larger branches nearly to the top of the tree. Close to Elden Spring at Flagstaff is a juniper of this sort which is 4 feet through east and west and is still growing actively in those directions, but north and south it is only a foot through and completely dead. The alligator-bark juniper is more promising than the other species and may become a valuable tree on more complete investigation.

The cedars are somewhat like the last-mentioned juniper. They are rather complacent, but do show some variations. The west coast cedars take a good deal of water-supply. Some extremely large ones are occasionally found, but they have not seemed promising. The rings are generally larger than the sequoia rings and for the same size the trees are not so old. Many cedars growing in the vicinity of the sequoias have been examined and the ring record is considered below the big tree record in quality.

Oak and other hardwoods—The oak is less generally distributed in the Southwest than the yellow pine, but there are large and important areas over which it is the available tree. Various samples collected seem very promising, but it has not been available extensively in the form of stumps and it is too hard to bore, so no final tests can be reported here. Kapteyn's first work in the Rhine Valley was on oaks, and in the last few years (1921) Professor William J. Robbins, of Columbia, Missouri, has traced a fine relationship between oaks and spring rainfall. This tree was used in the Swiss lake dwellings, and fossil oaks are very common, showing some of the best ring records to be found in museum specimens. Undoubtedly it is a valuable tree.

Beech rings in northwestern Pennsylvania show good variations and seem very promising. This is well to keep in mind, because there are great beech forests in South America whose rings may contain important climatic information.

Tropical hardwoods have been examined in museums in large numbers. The annual rings are mostly very hard to make out and naturally that is what we would expect where the trees have over-abundant rain and sun. Yet there are pines from tropical areas whose rings look very attractive and well worth a careful test for climatic effects. They grow mostly at higher levels. Two Araucanian pines from southern Brazil, showing 500 years of age, were measured in the Commercial Museum at Philadelphia. Their variations looked very attractive, but there was no success in finding cross-identity.

Cedar of Lebanon and archæological material—This cedar is chiefly found in mummy cases, which from the earlier dynasties show beautiful ring systems, very pronounced but somewhat complacent. The wood is not so good as yellow pine or sequoia, but as approximate dates are known its records are valuable.

The prehistoric ruins of the Southwest have large numbers of pine and fir logs used as beams. These offer the finest records and a very valuable collection has been made. Even the charred ends of beams that remain in some walls of burnt-out kivas give perfectly good ring records which permit the "relative" dating of the construction period. Juniper, cedar, and pinyon have been used in the same ruins and many sections have been saved, but so far little relative dating has been done on them. Engelmann spruce also occasionally is found, but it has failed to be of value. Several cottonwoods give too short sequences to be worth while. Certain buried pines from the vicinity of Flagstaff give very fine ring records with other interesting features.

LOCATION OF TREE

Regions which have been recently cut over will offer the best facilities in getting good specimens from the stumps. A full day or more may well be spent in marking the stumps from which pieces will be cut later by workmen. This selection is very important, for one wants a group that will cross-identify and at the same time will fully represent the forest and the general locality.

Homogeneous area—One needs, in the first place, to collect from a homogeneous area, that is, an area in which the various trees have somewhat similar conditions, enough to give similarity in rings, for on this recognition of the same rings in each depends assurance of climatic effects in the trees and reliability of dating of rings. To limit one's self to a homogeneous area means that the group will not extend to opposite sides of a large mountain. In northern Arizona differences of a few hundred feet in altitude do not usually affect the rings, but differences of 1,000 or 2,000 feet do sometimes affect them. Westerly or southwesterly exposures are somewhat preferable, as that is the direction from which the storms come and there can be no "shadow" or other local effect.

Wide sampling—On the other hand, the group should not be condensed, but should extend a good portion of a mile at the least, so that no alteration can arise from some special condition affecting a part of the group.

Grouping—The tree bored, or the stump cut, is better if not near other trees. Trees under 10 feet apart are apt to have an effect one upon another by undue shading or appropriation of moisture. This causes eccentric growth of the rings, throwing the major radius away from the

center of the group. Such eccentricity is rarely harmful to the ring sequence unless very conspicuous, but it may mean erratic or slanting growth and therefore is to be avoided as a rule. While the Arizona pines are naturally isolated, the sequoias are habitually close-grouped; but in spite of this the latter tree rarely shows any effect that can be attributed to nearness of other trees, unless two are almost in contact. But in the coast redwoods close grouping is doubtless an important cause of its failure to cross-identify.

The big tree is surrounded by dense vegetation in the basins and loose vegetation on the ridges; the coast redwood has a jungle about it; the yellow pines, however, wherever they grow, have sparse or actually deficient vegetation about them.

Ridge and basin selection—This is a question of soil moisture and underground drainage, most important factors in the life of the tree, for while other influences may alter groups of rings and completely spoil parts of the record, the moisture-supply in the soil may change the character of the entire record or even make it totally useless. The evident topographic features which control the situation are of course hill and valley, but to make it more specific by naming the extremes, it is called ridge and basin. Ridge and basin sequoias cross-identify perfectly, but there is a great difference in their immediate response to climatic changes, so that the ridge trees show much smaller average growth with vastly greater differences from year to year. This goes so far that the ridge trees nearly always omit many rings in the radius one chooses to study. Only by accurate cross-identification can these omitted rings be determined and correct dating carried past them.

In the yellow pines, ridge and basin contours have the same effect, producing quick-growing, complacent trees in the latter and slow-growing, sensitive trees in the former. With these facts in mind one can usually pick the kind of tree desired.

Bedrock and soils—Lavas and clay soils give usually a small complacent growth to the Arizona pines, while limestone and the porous soil above it give more sensitive growth, which may be increased in size by a richer soil.

Pines and altitude—The Arizona yellow pines at low levels, such as 5,000 feet, are so sensitive to rain that rings are frequently doubled by the two rainy seasons. This characteristic nearly disappears in 1,000 and 2,000 feet of greater elevation, where the most usable records are found. At still greater heights the accuracy of the rainfall record diminishes, as soil and air moisture are more permanent and the tree in its type of ring record becomes more like the California yellow pine and sequoia.

East and west mountain slope—In the southwestern part of the United States, the winter storms coming from the west supply nearly

all of the growth-moisture for the trees. The result is that the east and west sides of a large mountain have a distinct difference in climate which shows in the trees (see shadow effect, p. 108). At corresponding levels the west side is wet and the east side is dry. Around the San Francisco Peaks, in northern Arizona, the pines extend to 1,000 or 1,500 feet lower elevation on the west than on the east. Pines on westerly slopes are to be preferred as less likely to be altered by local conditions.

North and south mountain slope—Snow lingers longer on north slopes, and pine trees are able to live under such conditions at lower altitudes. But in the middle elevations of the pine belt no sensible difference has been noted in ring record between minor north and south slopes.

CONDITION OF TREE

Lightning scars—In standing timber this commonly appears as a white streak from top to bottom of the tree, about 1 inch in width where the bark has been blown away and the wood revealed. The heat of the electric flash has suddenly vaporized the sap and exploded the tree along this narrow line. This usually heals and has no important effect on the climatic record in the tree. The scar is easily recognized on the stump. It is very common in the "buried trees" found in the valley terrace above Flagstaff, which doubtless means that summer thunderstorms were more common in that particular past climate than they are now. Lightning scars are rarely seen in petrified wood, but the writer has a photograph of one in a beautiful specimen from Tertiary levels in Yellowstone Park.

Injured and fire-scarred trees—The major injury to western trees is from fire. This is not always caused by the careless camper or smoker, for the greater number of forest fires come from lightning. A single summer storm at Flagstaff has been seen to start fires in four different trees. In a precipitous country it is the up-hill side of the tree which is more likely to have fire injury, for it is the brush and leaves and needles collected there which hold the fire till it injures the tree. The fire scar is a large burnt area covering from 10° to 150° of the circumference and extending from 3 to 20 feet or more above ground. The tree may recover by covering a small area with new growth or by abandoning all attempts to reclothe the burnt section and using only the root system on the normal side.

Different trees and fire—Fire injuries rarely give trouble in the yellow pine, for they are largely on nearly level ground and there is little vegetation about them. Hence, there is little accumulation of rubbish and a general fire does not linger about an individual tree. The sequoias represent an enormously greater interval of time and so are more likely to show fire scars. Their ages are from 700 to 3,000

A. Fire injury on D–12 (stump) showing repair and gross rings and inclosed bark

B. Center of oldest Sequoia, D–21, showing ring grown in 1305 B.C.; three pins stand at 1300 B.C.

years, compared with 200 to 500 for the pines. The sequoias also grow close together, and in the basins are closely surrounded by other vegetation. So fire once in them lingers and injures the tree. Amongst thousands examined the uninjured trunk has been very rare, perhaps less than 1 in 10, as one looks on top of the stump and sees the history of each tree. The large groves of coast redwood show similar history. Though the custom of burning over the area right after cutting may lead to overestimation of the number of ancient fires, the impression is gained from hundreds of stumps that large fire injury is very nearly as common as in the giant sequoia.

In tree selection the effect of a lightning scar is negligible. The effect of a fire which kills small trees about but does not externally injure the tree under examination is to cause a slight possible diminution in size of rings. In this connection one remembers that fires are more frequent in times of drought and hence exaggerate climatic effects already in the trees. But the effort of a tree to repair a large burnt area changes the ring-size for some distance from the injury and sometimes all about the tree. Hence trees showing large fire injury should not be used.

COLLECTION PURPOSES

In securing records of climate in trees, necessarily length and accuracy of record are the two primary considerations. In the previous pages we have dealt with accuracy alone; now we deal with length, always modified by the necessity of preserving accuracy also.

Cycles and secular changes—The original thought in this study emphasized the tracing of cycles. These are found in relative ring-sizes which can be taken almost at once from the trees without a knowledge of the absolute rain or climatic equivalent. Perfect dating was absolutely necessary and all specimens have received the most careful laboratory handling. It was found by early tests that no especial gain was made by using large numbers of trees (Vol. I, pp. 21–22). But when Huntington studied the big tree for absolute values and secular changes, he did his work on the stump and obtained material which served his purpose without accurate dating. He used many specimens of all ages in order to work out a compensation for age, for that was fundamental.

Best collection methods—To allow for the needs of each of these purposes the best collection includes, first, long records; second, a few younger trees for the sake of certainty in dating the older trees if recent rings are compressed and doubtful and in order to develop a compensation formula for age of tree; and third, borings in the outer parts of living trees in order to get present-day climatic comparisons and to be perfectly sure of the ring of the current year, which sometimes fails to show on the stump.

Long-record trees—(1) Pines. If very large living pines are in moist valley-bottoms, they are not likely to be of maximum age, that is, over five centuries; but if they are near 60 inches in diameter and growing on a ridge or hillside, especially above a dry valley, they are likely to contain a valuable record. Of course, in such cases one checks the estimate by a core from the increment borer. (2) Sequoias. The oldest sequoias are not close to running water nor yet on exposed ridges, where stress of storms does not permit great age, but they are somewhat between these situations and usually near, though not at, the higher levels of the grove. This description applies well to the 3,200-year tree at Converse Hoist and the 3,100- and 3,000-year trees at Enterprise. A 2,800-year tree at Converse Hoist was nearer the top of a low ridge than one would have expected. A number of 2,200-year trees were well outside and yet not far from the thickly covered swampy basins, and they extended up the valleys to the highest levels of the groves. In the lower levels the trees were apt to have a large supply of ground water and some very large trees had only 1,500 to 2,000 years of age, such as the "Big stump" at Wigger's (General Grant Park) and the Dance Hall stump at Calaveras Grove.

Collection for age compensation—Samples for this purpose must obviously be taken from the immediate vicinity of the old trees whose records are to be checked, and in the same topography.

Climatic comparison—In collection for climatic comparison, one uses the general principles of selection already enumerated, remembering that one gets little if anything from young trees. Mature trees are much preferred, and even the largest and oldest, for in such cases the 9 or 10 inches of core cover a great number of years. On the other hand, very slow growing trees from the tops of dry ridges may be impossible to date without some neighboring younger trees, and it is safe nearly always to include a very few younger trees to assist in this operation. Trees very near a road are apt to be erratic from injury.

Age estimates in sequoias—Age estimates are a necessary part of collecting, especially in sequoias. The best criterion is the size of the outer rings, coupled with the total diameter of the tree. A promising tree should be over 20 feet in diameter above the bulging base, or near 25 feet at the very maximum. The rings at various places in the outer parts should get down to a few tenths of a millimeter or about a hundredth of an inch. On most of the very old trees there is a burnt space in which a few chips or bits of charcoal will give a sample of the rings. An increment borer is still better and may be used through a thin place on the bark of a living unburnt tree. The largest tree, showing over 30 feet in maximum or bulge diameter, if near running water, is not likely to add much to our climatic record. But if such a tree is on a dry hillside its age is worth investigating, and if it still promises well, some apparatus for boring it to the center could be devised.

III. RADIALS

SELECTION

An essential part of this study of climate and trees has been the laboratory work on the rings, by which the actual wood from the tree is placed under microscope and measuring-machine. In this way specimens from different trees may be compared together and an accuracy reached which would be hopeless in work on the stump. By laboratory means, cross-identification and correct dating are obtained before measuring and the measuring can be done to any desired accuracy which the rings permit. Hence it is essential to secure ring specimens which represent the tree, to get them to the laboratory without injury, and then preserve them in such a way that they can be used over again or referred to subsequently for any desired purpose.

Definitions—It is obvious that such ring specimens must be cut across the rings in order to display the proper sequence. The ideal form, therefore, is a radius of the tree, carrying an unbroken series of rings over all parts of the tree's history which are worth while. Such pieces are here referred to as tree-samples, ring records, radial pieces, or simply radials. Of course, they may take different forms, depending on various conditions of collection; for example, whether they come from living trees, fallen trees, or stumps.

LIVING TREES

The main point in sampling living trees is to get a short radial sequence of rings without injury to the tree. The best instrument for this is the Swedish increment borer, which will be more fully described in a subsequent chapter on instruments. These borers will not go into hard woods nor even into junipers, but they work well in pines.

Direction of boring—If the tree is on a steep hillside, it is usually more convenient and customary to bore on the up-hill side. Theoretically there could be a difference in the rings between the up-hill and down-hill side of a tree, but no such difference has been noticed. Other things equal, it is well to eliminate the possibility by being consistent throughout a group. If the ground is generally free from steep inclination, one should adopt a certain compass direction and use that consistently in the group. Early investigation showed about Flagstaff a slight average increase of growth on the north or northeast side of a tree, due to lingering of snow in the shade of the tree, but this is probably of little or no importance in radial selection.

Height above ground—Height from the ground, if well below the branches, has not been found to introduce error. So far as observed,

the differences at different heights are less than the differences between different trees. Of course, in most cases the differences are practically none at all. This subject of taper study or vertical uniformity will be treated on a later page. A boring within a foot of the ground makes one feel that complex and difficult corrections are needed because of the root influence, and the ring record therefore is inferior. On the other hand, if the boring-hole is made over 2 feet from the ground, it may injure slightly the value of the tree for lumber. The average height of pine stumps about Flagstaff is 16 to 20 inches, sometimes going to 2 feet. The lumberman knows that interior defects increase toward the root, and there is always a little waste at the lower end of the butt log. In choosing the exact spot to bore it is better to try a slightly projecting part of the trunk, for there is less danger of encountering absent rings which might render dating difficult. One must be careful in boring fallen trees to note whether they still have roots in the ground and are dry or moist. If they are still rooted or not thoroughly dried, the sapwood may be distorted with irregular growth or irregular swelling from moisture.

Root rings—Ring sequences have been identified from roots of trees and in some cases such records seem usable. These, however, have never been included in the averages, from the feeling that root rings, even in large branches of the root, must be subject to other conditions than the trunk and may not be consistent. Sometimes, in well-watered pines, early rings in the lower trunk near the root may be very large.*

Crown rings—Rings near the top of the tree and in larger branches show close similarity to rings in the lower trunk. Though their actual size is smaller and sometimes microscopic, the sequence of sizes, of the tree record, is nearly the same (see fig. 1, p. 24).

Boring the sequoia—Using the increment borer on the sequoia has rarely seemed worth while, except for some special purpose, such as tests on young trees for infancy rings, estimates of age, and so forth. The reason is the enormous thickness of bark of the sequoia, especially in the lower 15 feet, and the distortion of rings due to bulges in the same region. With a ladder one could get useful specimens.

The 1-inch tubular borer—The tubular borer so far has not been satisfactory on living trees, not because it hurts the tree but because it is slow and difficult in operation. An 18-inch core from a 350-year

*This was observed in a tree which once stood in the flat south of the county hospital at Flagstaff, about 2 miles north of town. The tree was cut down in the 1880's and was renowned for its size. Recently Mr. L. F. Brady copied on paper the rings in the stump, which was badly burned. When I saw it, the stump had been blasted out and thrown away, but fragments showed extremely large and complacent rings near the root. The dating was uncertain, but it was probably nearly 500 years old at time of cutting.

tree in the lava-bed near Flagstaff took nearly two hours of very hard work. When it is needed, no doubt a suitable borer will be easy to construct.

FALLEN TREES

The chief work on fallen trees was done in the Calaveras Grove of sequoias. The bark of these trees lasts 10 years or so after the tree has fallen. The sapwood weathers off in something over half a century. Heartwood has lasted a hundred years in the open air, but in the case examined the wood was badly decayed and little of it was left, as shown in Plate 2. It has been a disappointment not to find logs lasting far longer, for example, a thousand years; for if very large ones could be found they might have very old ring records. Apparently even the wonderful qualities of the sequoia sap will not preserve the wood indefinitely. Fallen trees give the chance of boring at any height and from that arose the vertical uniformity or "taper" tests given below.

In the Calaveras Grove there were three classes of fallen trees, so far as dated records were concerned: (1) old tree-trunks without sapwood, so that the date was unknown; (2) trees showing sapwood, with approximate date of falling; and (3) those whose date of recent falling was known. So to insure correct dating, all three were included. Thus an overlapping group was obtained, which by cross-identification produced correct dating for the Calaveras trees. But all this care proved unnecessary, for the first radial examined, as well as all the rest, readily dated in terms of the trees in the southern groves.

STUMPS

Collection from stumps permits many forms of which the full section is only possible in the case of small trees. Thus full sections have come from the white pines of the American Arctic and from the beams of the ancient ruins. At the start, full sections were made of the early Arizona yellow pines, but they have proved so unwieldy and difficult to provide space for that even from these radial samples have been cut, which give the ring sequence from center to outside. So methods of collection necessarily adapt themselves to the size of the trees. In the vast majority of cases a piece is cut from the stump, and that process is described below.

Shape of stump—In felling a tree a notch is first cut on the side toward which the tree leans and will fall. This undercut goes perhaps one-fourth way through. In big trees it becomes large enough for men to stand up in. Then a two-man saw is started in horizontally from the opposite side at a slightly higher level. As the saw enters the tree, the weight of the tree will pull away from it and not make it bind. Sometimes the tree is leaning so heavily that as the saw gets

deep into the trunk, the strain on the remaining wood is tremendous and it cracks badly in lines parallel to the saw. If its own weight does not keep it from binding the saw, steel wedges are driven in the cut to force the tree up on that side. The tree usually begins to fall some time before it is completely cut from the stump, the portion that is uncut breaking off at the level of the undercut. The stump then shows the sawed surface for two-thirds of the diameter on one side, the chopped surface of the undercut a foot or two lower on the other side (in the big trees), and between these a broken and splintered space where the wood broke in falling. Sometimes the tree does not fall of itself when the saw is approaching the undercut, and then instead of sawing it completely in two, which would be dangerous, sticks of dynamite are placed in the remaining attached portion and the tree blown loose. This is apt to blow the stump to pieces, as happened with D–18 of the early sequoia group. That sample was therefore cut from the end of a log which had been 50 feet or so above the ground. So nearly all stumps have a flat top, which will exhibit from a little over one-half the diameter to more than three-quarters. This restricts the choice of radius a little, but reduces the amount of sawing in making the cuts for the radial piece.

Selection of radius—In visiting a cut-over area with multitudes of stumps, the first consideration is the apparent excellence of the rings and the ease of cutting a radius which contains good readable ones. In the Arizona pines this gives very little trouble. In these trees the radius chosen and marked merely fulfills consistency regarding points of the compass and contour of ground, and avoids fire-scars, lobes, and knots in the stump-top itself. The piece cut out very often takes the whole diameter. In the sequoias perhaps only 10 per cent are without defects, and the inspection of stump-tops becomes an important matter requiring from half a day to a couple of days. Deep fire wounds in healing often inclose large masses of bark, and frequently such scars have a considerable area of sapwood which has never turned to heartwood. Such defects are always interesting for the history they tell and are easily avoided in picking a radius. This appears in the photograph of sequoia D–12 in Plate 1.

One of the greatest difficulties with small fire-scars is the extensive break they sometimes cause in the continuity of the rings. The fire so alters the growing layer that for some distance away from the burnt area the wood will crack and it may be very hard to say whether the crack is within one annual ring or between two. Lumbermen say that this cracking or checking takes place in the living tree. It is attributed sometimes to temperature changes—frosts in the weakened wood—and sometimes to wind. At any rate, in a weathered stump such a crack becomes worse and makes it difficult to use otherwise good material. In such cases it is always best to cut a separate small

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A. Weathering in 60 years, CV–4; bark gone, sapwood mostly gone; Calaveras Grove

B. Weathering in 125 years; CV–3, sapwood and center entirely gone; Calaveras Grove

radial piece extending a hundred years or more on each side of the questionable years, from some other perfect part of the stump. This new piece bridges over the doubtful point. It is just such procedure as this which makes the dating entirely reliable. Knots or buried branches give practically no trouble, except at the very center. The lower parts of a sequoia whose bark has turned to the notable tan color of youth seem to have no branches. They probably all disappear as the rings lose that immense size called the "infancy" stage. So in selecting a radius for cutting it is highly important to escape gross-rings, lobes, and fire-scars. Items to be recorded are the length of radius, bulges or slope, direction and amount of slope of the ground, and neighbors. If the tree has grown eccentrically one would slightly prefer an average radius if the rings are not too much inclined. Bulges as a rule are below the level of cutting, but they may affect the slope or vertical inclination of the rings from the enlargement they produce in the base of the tree. In recent collections the slope of the outside has been measured with a simple inclinometer.

The v-cut—Even in small trees the **v**-cut illustrated in Plate 3 is now the standard form found practicable. Such small pieces are **v**-shaped or triangular in cross-section and made by two slanting cuts with a saw, meeting at a depth of 1 to 6 inches below the surface. With a long saw on large stumps the slanting cut is made by driving two spikes at a slant into the stump top, placing a board against the spikes, and resting the saw against the board.

The size and weight of the radial piece cut out depends on the spacing of these cuts. Two inches is taken as the standard practical width and depth in big trees. If the **v**-cut is made from a weathered stump, as is usually the case, the cracks in it allow it to drop to pieces as the saw releases it. To aid in fitting these together the distance from the bark in inches is marked on each piece as it comes loose. These pieces are collected by an assistant who accompanies the sawyers and are all put in one bag, which is marked with the radial or tree number. These small bags are finally collected in a large canvas bag for transportation.*

PREPARING THE RADIAL

Arrived at the laboratory, the pieces are taken from the sacks and carefully fitted and glued together and wired or screwed to a right-angle mount of standard size which permits stacking. This mounting consists of a base and back, each 4 inches wide by 8 feet long, 1-inch wood, with heavy square end-pieces. These mounts, being all of the same size, will stack one on top of another against a

*When this work is done by a lumberman who can not bother with bags, the spacing of the cuts should be wide enough to make the specimen hold together.

wall or with very slight bracing, so that at a glance one may look over the entire collection.

The original surface of the stump is placed downward in the mounting, thus showing the freshly cut surfaces, which at a little distance below the stump-top are in better condition. One or both of these surfaces is smoothed with a rasp or file; then after careful inspection of the rings a line or band is marked where the measuring and dating will be done. For this purpose two parallel lines a half inch or more apart are put on, as nearly straight as possible. The space between these lines is then shaved with a sharp razor. This leaves a superb surface for measuring the rings. The lighting direction is important, but by a little practice the best position is readily found. The only special caution at this stage is that each break in the wood which has been glued should be marked and shaved along the crack so that dating and measuring can be carried past it without the slightest chance of error, but this rarely presents any difficulty.

RADIAL STUDIES

CIRCUIT UNIFORMITY

By circuit uniformity is meant the close similarity of the ring records in all directions from the center of the tree. The fundamental importance of this was fully recognized in the first formative period of this investigation. Cross-identification between different trees was first used as an essential in 1911, but this identity between different radii in the same tree was noticed in the very first trees measured in 1904. To describe where it has been found would be to enumerate almost every tree worked upon. Even groups that do not cross-identify well show circuit uniformity. This does not mean that the different radii are equal, but that the relative ring values are closely the same in all directions. So the present topic is for the purpose of calling attention to a few exceptions. Circuit uniformity is modified in three ways—by eccentricity, lobes, and gross-rings.

Eccentricity—Slight eccentricity is very common. It becomes noticeable in perhaps one-third of the stumps examined and occurs in perhaps one-quarter to one-twentieth of the trees sampled. It merely means more growth on some one side than on the opposite. It is a common effect of group pressure and frequently occurs when two trees grow very close together. The maximum growth is then away from each other. It may be due to other causes. In the first 25 Flagstaff yellow pines there was 12 per cent more growth to the northeast than in the opposite quadrant, attributed to better moisture conservation in the shade of the tree. Eccentricity, unless excessive, need have no effect whatever on the tree record, and even if excessive it can usually be evaded. The most extraordinary case ever noted was a

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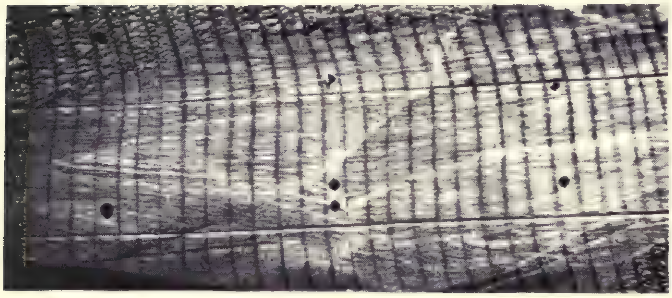
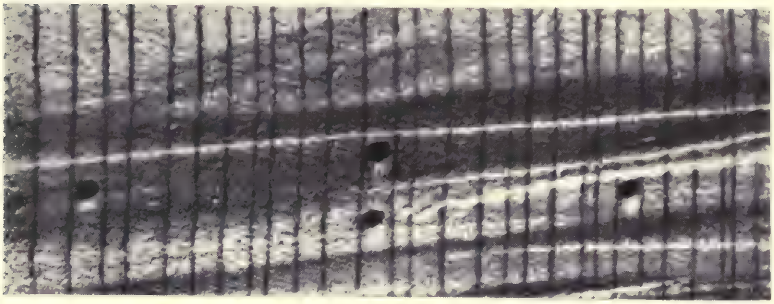
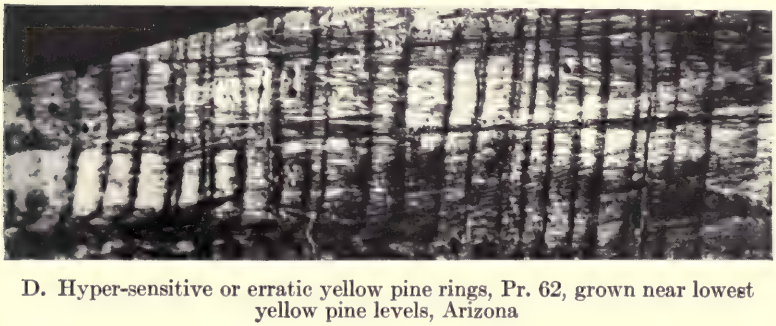
A. Forms of v-cut on stumps



B. Complacent sequoia rings, D-8, grown in wet basin



C. Sensitive sequoia rings, D-4, grown in uplands



D. Hyper-sensitive or erratic yellow pine rings, Pr. 62, grown near lowest yellow pine levels, Arizona

Scotch pine from Ös, Norway, which had a 3-inch radius on one side and a 9-inch radius on the other. The maximum radius was used and it cross-identified in a perfectly satisfactory manner. Several of the trees from that locality showed a very rare characteristic in having the eccentricity change its direction as the tree grew older, due probably to change in surrounding growth. This was less easily avoided. Forest Service men usually prefer a mean radius in eccentricities, but in this work it is not desirable, because in that kind of a radial the rings are apt to be inclined, making perpendicular measurement more difficult.

Missing rings—In eccentricity the crowding in the shorter radius causes some rings to disappear altogether instead of merely becoming more minute. The same failure of rings is very apt to occur between lobes, especially in junipers. Hence in boring trees it is safer to choose the lobe itself than the depression between lobes.

Lobes—In the case of lobes, or the scalloped outline of a tree-trunk, the variations observed in eccentricity are greatly exaggerated, in fact, so much so that trees like juniper and pinyon that go strongly to lobes can not well be used in ring studies. In an extreme, a given ring can not be traced from lobe to lobe. Such a tree of course has doubtful value.

Pines and sequoias, however, have only a negligible lobe effect, except during the "infancy" period of the sequoias, when the lobes are very marked. They disappear in the early "youth" rings, which are really the earliest ones of any chronological value. When not pronounced, either the lobe itself or the depression between two lobes may be taken as the location of a radial, for the rings remain at right angles to its direction.

Root influence—Lobes are usually more pronounced at the base of the trunk and show evident connection with the roots. Since the root supplies the sap which passes up the trunk and, in passing, forms the ring, the rings, it would seem, depend upon the way the sap spreads out around the tree as well as upon vertical movement. So in old trees whose rings are naturally crowded, we find some missing here and there in the circuit without much lobe effect being evident. In the general use of at least five trees in a group, such lapses practically always come to light.

Gross-rings—A difficulty in the selection of radius in sequoias has been occasional radii where the rings are greatly enlarged. These are called "gross-rings." They are probably associated with the success of some certain root and therefore formed lobes or projecting curves about the trunk when the tree was growing at that size. Sometimes these areas extend directly to a projecting curve of the stump outline and their relationship is evident. They not merely exaggerate

immensely the average growth in certain parts of a radial line, but they do not hold to one radial direction and any straight line; cutting them at an angle has inclined rings, which therefore have an added fictitious size.

Gross-rings only moderately represent climatic change. In an old study it was found that gross-rings in one tree corresponded to similar rings at that date in about half the other trees. They probably occur when for some reason the tree is having rather successful growth, and so they roughly indicate favorable conditions. It would probably improve the curve of the tree's growth if they were reduced to a size somewhat less than half-way between normal and their actual size. The inclination which they so often exhibit can be corrected by measuring in a different angle or by a multiplying factor. But either one adds greatly to the labor of handling large quantities of data in tables.

Spiral gross-rings—A prehistoric section, H–9, from the Aztec ruins has a spiral of enlarged rings, which took about 12 years to make the circuit. It is impossible to tell from the specimen which way the enlargement rotated. The 9-foot Sitka spruce in the American Museum of Natural History shows at some 8 or 10 places about the circuit spiral enlargements with a very slow rotation.

VERTICAL UNIFORMITY

Outside tests—The close resemblance between ring records at different heights in the same tree was assured for the yellow pine a score of years ago, but has only recently been tested formally for the sequoia. During the trip of 1925, a windfall in the Springville region offered such a good opportunity for tests of this sort that it seemed worth while to take advantage of it. This tree, whose uniform trunk was about 15 feet in diameter, had been blown down in 1901, according to Mr. Elster, close to the houses at Enterprise, which had been started as a mill-site some three years before. The tree is lying there in excellent condition. The Swedish increment borer was used at 9, 15, and 35 feet from the base of the roots and thereafter at each 20 feet, to a distance of 235 feet from the base. At 255 feet small pieces were cut with a saw, in wood which had been a living branch and in a dead part which had been the main stem. This last showed nearly a thousand years in the radial and has not yet been identified, probably on account of the smallness of the rings. Yet 900 years in the living branch were readily dated, and at 20 feet below this point the cross-identification is perfect, though the branches begin nearly a hundred feet lower down. The lowest boring was well within the root system, close to ground-level, and does not identify well after 1700. With this exception, similarity in heartwood record, which extends to about 1800, is striking at all heights above the ground. But the sapwood rings show profound differences, due it is thought (p. 101) to irregular

swelling from the moisture which has filled them for years. Figure 1 shows parts of the heartwood curves, from 1550 to 1590, including the year 1580, which is very distinctive when taken together with 1548 and others. Figure 2 shows the variable sizes of sapwood rings, interfering greatly with dating and presenting a most unusual condition in the sequoia.

The curious fact became evident that the tree grew in places a long time after falling, for most of the borings show a serious injury about 1901 and some show no growth after that. But some show continued growth up to 1915. This appears in figure 2. Evidently roots still in the ground supplied moisture and supported growth for more than a dozen years after the tree had fallen.

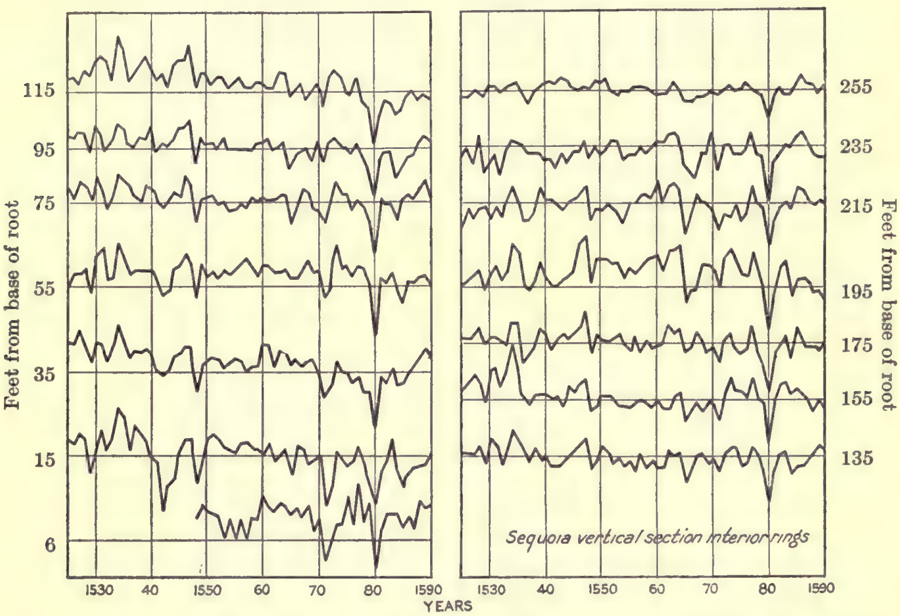


FIG. 1—Heartwood rings at different heights in the sequoia; total height 265 feet; vertical uniformity nearly perfect. Scale × 7.5; horizontal line with each curve represents 1 mm. growth

Naturally, this matter of longitudinal or vertical uniformity was considered and tried out informally in the early work on this subject, and, so far as the eye could tell, the same rings existed at different heights. The fact that cross-identification applied equally at different heights in the trunk of the tree was held sufficient at the time. For example, D–18 and D–20 were each cut about 50 feet above ground-level, and yet they cross-identify and otherwise appear exactly as sections near the ground. The recent work of MacDougal and Shreve on the longitudinally bisected tree is adding to our knowledge, and it

is desirable to see such studies applied to mature big trees and to yellow pines, each in its natural home.

Central tests—A recent test at the center of a sequoia came about in this way. Stump numbered D–22, whose picture is shown in Volume I, Plate 7, *A*, was sampled in 1918. It had over 3,000 rings, but other innermost ones were missing on account of a large hole in the center. The earliest ring found was 1087 B. C. The estimated radial loss in wood at the center was 12 cm. (some 5 inches) or about 75 rings (Volume I, p. 52, table 5). The "butt" log from this stump was lying not far away. In 1925, it appeared that in the upper end of this

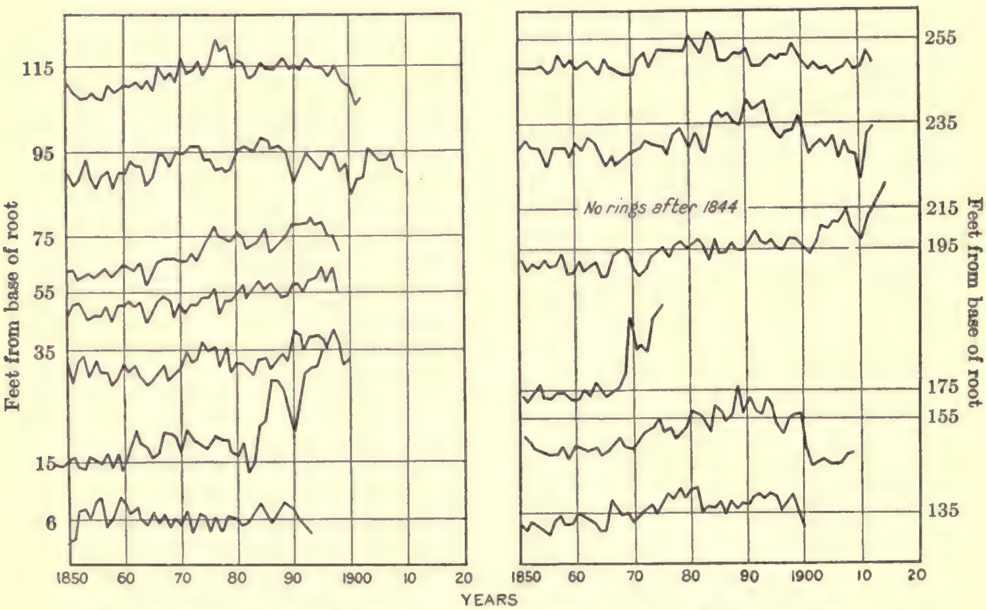


FIG. 2—Sapwood rings in fallen sequoia; irregular growth after falling (in 1901) is shown with distortion due to water-soaked condition. Scale × 7.5; horizontal line with each curve represents 1 mm. growth

log there was no hole and the rings originally filling the hole in the stump might be found and measured at this point. So a special cut was made crossing the center and extending a few hundred years along the best radius. This direction proved to be away from the original radius, but in the sequoias that practically never makes any difference. This cut was 12 feet above the original cut. It was hoped that the new piece would carry a record even beyond D–21, the oldest of all the sequoias. But this wish was not fulfilled, although this center V-cut proved very interesting. It cross-identified with perfect ease and entire certainty. The central growth was in 1115 B. C. So only 30 years were gained, but it thus carried a record back very nearly as far as D–23 nearby, whose innermost complete ring was 1122 B. C.

2.6

A. Fallen sequoia, Enterprise, on which vertical uniformity tests were made

B. Sequoia "California," Enterprise; and Mr. C. A. Elster

At the same visit in 1925, it was remembered that D–23, whose earliest ring has just been given, also had a large hole in the center, with an estimated loss of 14 cm. or 80 years. This D–23 or Centennial stump, has a large fragment lying near it on the ground, but a search showed that only some outside pieces were there and the central parts were entirely missing. Thus, there is no chance of extending the record of D–23. In this connection it may be added that the oldest tree, D–21, whose earliest complete ring is 1305 B. C., has only an inch missing at the center, perhaps a half-dozen years, and so there is no chance of material extension of that record. The central part of that stump is carefully preserved and mounted in the laboratory.* It is shown in Plate 1.

A tree known at Springville as "California" and numbered D–47 in my series was cut years ago for the purpose of building a sequoia hut. It stood isolated, about half a mile from the Centennial stump in a southerly direction. The stump has a very high, projecting center, with steep ax-cut slope to north and a walk-way all around where slabs of wood were removed. The top and nearly all the trunk lie off to the east, with a smooth sawed face 15 feet in diameter, as shown in Plate 4. My **v**-cut was made on this face, extending past the center. Almost at the last moment of my visit one of Huntington's grooves (but no number) was found on this stump, showing that he had counted the rings. So for comparison we made a short central **v**-cut. This was about 12 feet above the ground and also about 12 feet below the full radial taken from the log. This will be studied in connection with ancient records.

*The smallness of this hole where the infancy rings used to be, suggests that this cutting-level was 20 or 30 feet high on the tree when it was a sapling. If so, the ground about this tree has filled rather than eroded. The adjacent contours make this possible.

IV. RINGS

During and following the processes of cross-identification and dating, described in the previous volume, the best ring records are picked out by a form of selection, first between the different trees of the group, and second between different parts of each tree record.

SELECTION IN GROUP

During cross-identification it is very easy to see which specimens conform best to the group type and which ones conform so little as to be discordant, for in all the groups used a group type is evident. It becomes, then, easy to recognize any specimen which for some reason or other, perhaps a fire injury or a different water-supply, does not agree with its group. Such specimens are obviously so far from the average that probable errors are diminished by their omission and their values are not included in the group average. Such individuals are usually very few in number, in the majority of groups none at all, and they include of course the ones which can not be cross-identified.

MEAN CONFORMITY

In judging whether any tree should be retained in the group a criterion called "mean conformity" has been very extensively used. It is the agreement which any individual shows to its group or type. In effect, it is an added weight given to individual specimens which have the best support from other members of the group.

Quantitative conformity—An actual numerical value of this conformity could be derived by mathematics (by mean residuals from group averages), but it would be a long process and the results at the present stage would not be worth the labor; for after familiarity is reached a conformity coefficient can be estimated, as in a multitude of different scientific observations. However, in connection with the selection of best sequoia records for comparison with Arizona pines, a quantitative value was reached in a practical way. The Arizona variations were kept fresh in mind as each sequoia record was reviewed. The number of Arizona features found in each sequoia for each of the last five centuries was carefully recorded and the total placed against each sequoia as its weight or conformity. Those having the best conformity were then selected for certain comparison problems. This is a good practical method. Other selections have not been made on so large a scale and did not need such formal organization, but nearly all have been based on some modification of this process.

Weighted means—After mean conformity of each member of a group has been obtained, it may be used simply to exclude poor

records, so that the average of the remainder will be improved. If some approach is made to a numerical value of this conformity, then it may be used to obtain a weighted mean. This was done in the case of the four best sequoias selected for dating comparisons with Arizona. This was a long process, but its application did not make enough difference for one to feel that its universal use is necessary.

MEAN SENSITIVITY

Another criterion which helps in selecting the best record has come into practical and important use, even though the computation of numerical values is a refinement not usually applied. It is called mean sensitivity (see also p. 104) and is an inherent character in each individual. It may be defined as the difference between each two successive rings divided by their mean. The quotients are arranged in groups of 10 or some other number of years, and listed as the mean sensitivity of that period. Plate 3 shows the appearance of rings of different sensitivity. The first section (*B*) came from a sequoia which grew in a swampy basin about 15 miles east of the General Grant National Park. The tree had a "complacent" growth, with all rings of nearly the same size. Its mean sensitivity is 0.11. The second is a sensitive sequoia which grew near the top of the mountain, 800 feet higher up, with a limited water-supply and therefore more dependent on the moisture of each year as it came. Its rings have more character and individuality, and the changes from ring to ring are much more evident. The mean sensitivity is 0.33. The third is a hypersensitive dry-climate yellow pine near Prescott, one of the 10 used in the curves of Prescott tree-growth already described. It grew near the lowest limit of the yellow pine. Some of its rings, such as 1841 and 1857, are so small as to be found with difficulty. Its variations from year to year are extremely large, and its mean sensitivity is 0.64.

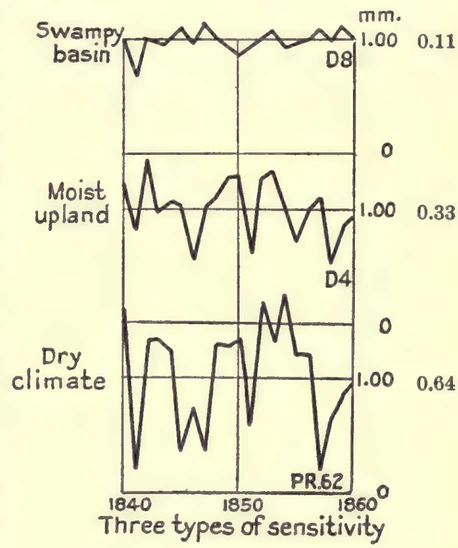


Fig. 3—Mean sensitivity and soil moisture

The way these variations in sensitiveness look in plotted curves is shown in figure 3, in which the curves of growth of these three trees show percentage departures, each from its own mean. The different character resulting from the different environment is at once apparent to the eye.

Practical application—The practical method of handling mean sensitivity is to take the sum of all the changes in 10 years without regard to sign and divide by the sum of the 10 years' growth. This is the way it has been used in the limited mathematical tests. As a matter of fact, high sensitivity in a ring sequence is often apparent to the eye, as anyone can see in the illustrations, and in much exploring work the eye estimates have been the practical and rapid way for using this criterion in judging between ring records.

SELECTION WITHIN RECORD

The recognition of the preferable parts of a sequence of rings comes from an understanding of the natural divisions of a tree's ring system due to age and the recognition of the various kinds of errors and difficulties in the rings themselves. Most important of all perhaps is a knowledge of the meaning of rings in terms of their environment. This last part of the subject is discussed in Chapter VIII.

PARTS OF A TREE'S RECORD

All parts of a tree's record are not equally useful. For purposes of description a good record may roughly be divided into infancy, youth, maturity, and age. These are largely recognized by the size and character of the rings.

Infancy rings—These are most easily found in the sequoia and consist of a central series of extraordinarily large rings, sometimes 2 cm. in width, 10 to 50 in number, showing practically no variation except a successively diminishing size. They are very soft and in very old trees often disappear, leaving a conical hole extending to some height from the ground up into the tree. This is probably the explanation of the rather common central hole, sometimes untouched by fire, as shown by study of stumps. This was formerly attributed to other causes, but some recent identification of the central parts of very old trees described above under "Vertical uniformity" have favored this view.

Youth—The youth of a tree is evidenced by large complacent rings, usually largest in the center and outwardly growing regularly smaller. Speaking from an economic point of view, the tree at this time has to build a large trunk in order to support the growing top and resist wind. It is true, as Antevs pointed out, that at this stage the tree shows large, less sensitive rings. In the yellow pine this period is likely to be 20 to 40 years, but even in these immature rings in many trees cross-identification is perfect almost to the center. This is not always so, and often it is best to drop the inner 20 rings.

The youth rings of the sequoia cover perhaps 300 to 800 years. It is the region where the rings are large and show a gradual diminu-

tion. Cross-identity carries through it usually with perfect ease. It is not always easy to recognize the end of this period. In rare cases a tree gets down to small growth in 200 years. It is possible that tests of mean sensitivity would provide a means of judging. In addition, actual climatic change enters here as a variable. A considerable number of the dated trees started near 300 B. C. and show the reduction in ring-size near 400 to 600 A. D. It is probable that there was a climatic drying at about that time which helped these trees to reduce ring-growth.

Maturity and age—Maturity in pines and sequoias covers the time from the attainment of full height to the decay at the top which indicates old age. During this period the rings have their best sensitiveness, though almost equal sensitiveness may last into old age, when the rings become smaller and possibly a trifle less sensitive and yet a trace more erratic. That is, there are longer periods with little variation, broken by a little more frequent complete disappearance of a ring from the sample under study. The growth has gone to some other part of the circumference. These are the unusual cases. It has never seemed desirable to discard the outer parts of a tree so long as the rings were certainly identified.

RING ERRORS

Superfluous rings—The one fundamental quality which makes tree rings of value in the study of climate is their yearly identity. This is sometimes disturbed by the presence of too many or too few rings. Superfluous rings are due to doubling. This is a climatic phenomenon to which some trees are especially liable, probably from their location and rapid growth. But let us keep clearly in mind that superfluous ring formation is the exception. Out of 75 trees collected near Prescott, only 4 or 5 were discarded for this reason. Out of hundreds near Flagstaff, none have been discarded on this account.

Nearly 200 yellow pines and spruces from northwestern New Mexico have produced no single case of this difficulty. The sequoias from California, the Douglas firs from Oregon, the hemlocks from Vermont, and the Scotch pines from north Europe give no sign of it. On the other hand, 10 out of 16 yellow pines from the lower levels of the Santa Rita Mountains south of Tucson have had to be discarded, and the junipers of northern Arizona have so many suspicious rings that it is almost impossible to work with them. Cypress trees also give much trouble. Trees whose extra rings can not be exactly identified are always excluded in part or as a whole.

Missing rings—The other difficulty connected with yearly identity is the omission of rings. Missing rings occur in many trees without lessening the value of the tree, unless there are extensive intervals

over which the absence produces uncertainty. A missing ring here and there can be located with perfect exactness and causes no uncertainty of dating. In fact, so many missing rings have been found after careful search that they often increase the feeling of certainty in the dating of rings.

Missing rings occur when autumn rings merge together in the absence of any spring growth. This rarely, if ever, occurs about the entire circumference of the tree. There are a few cases in which, if the expression may be excused, I have traced a missing ring entirely around a tree without finding it. I have observed many cases in which the missing ring has been evident in less than 10 per cent of the circumference. Some are absent in only a small part of their circuit. I have observed change in this respect at different heights in the tree, but have not followed that line of study further. It can be studied in the longitudinally bisected tree. A missing ring is often represented by a slight enlargement of the red autumn ring of the previous year.

One sees from this discussion what the probable errors may be in mere counting of rings. In the first work on the yellow pines, the dating was done by simple counting. Accurate dating in the same trees (19 of them) later showed that the average error in counting through the last 200 years was 4 per cent, due practically always to missing rings. A comparison in 7 sequoias between very careful counting on the stump and accurate dating in 2,000 years shows an average counting error of 35 years, which is only 1.7 per cent (Volume I, pp. 15 and 45).

Simulated doubles—In the process of counting and dating rings in Arizona pines, two sharp red rings sometimes occur close together, giving the appearance of a double and leaving one in doubt as to whether one year or two is involved. In such cases the following probabilities apply: If the tree has other obvious doubles, the case in hand is likely but not certain to be another doubling. If the two red rings are unequal in size and the smaller one is inside, that is, nearer the center, it is likely to be a real double formed by the spring drought. If the smaller one is outside the larger, it is probably a separate year. If the two rings are equal and either one shows a further doubling, the two rings in question are separate years. If the case is still doubtful, cross-identification may settle it. But if that fails, the doubtful part should be discarded. The most tantalizing case of this kind that I have is an early historic beam from Pecos, KL–I, in which all kinds of doubles are exhibited.

Reinforced rings—Certain groups of prehistoric specimens from the Wupatki National Monument, northeast of Flagstaff, show heavy reinforcement in the youth rings of many trees. That consists of very hard tissue formed during the rapid spring growth, so that each

ring is greatly expanded in one direction and somewhat diminished on the opposite side. This gives the appearance of a series of crescents on one side of the tree section. It usually interferes completely with the rain record in the tree, but at the same time has a strong climatic significance as an indicator of heavy spring winds.

Other false rings—Other abnormal rings are sometimes produced. Sequoia radials occasionally show certain "pitch" or "pith" rings. These are white, very narrow, and totally different in color from the rest of the wood. If they seem very soft, they have been noted as pith rings; if hard, as pitch rings. They may come either within a year's growth or between two years. They therefore are very annoying, for they destroy the count, it being impossible to tell whether the normal rings on each side belong to one year or to two. I have made it a rule to discard entirely regions of ring record thrown into doubt by such rings. Doubtless they come from injury and usually from fires. In the yellow pines no similar rings have been noted, but in each tree abnormally large rings occur close to large fire injuries during the early period of recovery and diminished rings in other parts of the tree circuit.

Effect on means—In all cases of ring errors that leave any uncertainty in dating, the uncertain part, or even the whole tree, is omitted from the means. In large groups, of course, the omission of a tree is usually a small matter, but in the early years of the group record it may be serious, for the number of individuals decreases as we go back to earlier and earlier dates. In such cases only the uncertain part is omitted. But here another difficulty is introduced, namely, the break in the averages at the beginning and end of the omitted part. If the tree in question agrees very closely with the mean of the rest in size of rings, the break does not introduce error; but if it is very different, it has to be merged with the average of the rest in some way. This becomes the same problem as that of introducing a tree of late starting-date into a long group record.

V. INSTRUMENTS AND TECHNIQUE

In dealing with the 175,000 growth-rings, dated, measured, and used in these volumes, special tools have been adopted or developed at every stage of the process to secure material and to hasten and improve results.

COLLECTING TOOLS

Saws—The articles needed in field trips include a chisel for marking numbers, paper and cloth bags for holding fragments cut from individual trees, a recording notebook, marking crayon, a shoulder-bag, camera, and various saws and borers. The best handsaw is known as a flooring saw, in which the teeth are on a curved edge of steel, as shown in Plate 2, *A*. With this, one can make a **v**-cut in the middle of a stump without touching the edge at all, or the saw can cut in from one side to the center without touching the other half. In working without help this has saved many hours of labor and energy. The convenient size of saw has a blade about 20 inches long. A 3-foot cross-cut saw used by lumbermen does at times prove very useful, but its extra weight and awkwardness in packing have always been against it.

Swedish increment borer—Since 1920 the Swedish increment borer has been used extensively to get records from living trees. It is very successful in softwoods such as pine and fir. Hardwoods and juniper are too tough for penetration without great danger of breaking the instrument. The cores obtained are very slender, smaller than a pencil, and reach to slight depth in large trees, but the method of mounting has been raised to such a degree of efficiency and the collection of material becomes so rapid that the deficient length and occasional worthless specimens are counterbalanced. In most regions the increment-borer material can be supplemented by a few cuts from stumps carrying the tree record back into the past as far as the forest permits. Thus the borer supplies the contemporary record, that is, the last 100 years or so from many trees, and the saw supplies the historic record going back for centuries.

In countries where native timber has been cut off and the yearly "crop" of lumber comes from planted and reforested areas, it is very important to know how growth is progressing. So Swedish ingenuity produced this tool for sampling the outer rings of a tree. The borer is a tube of 4 to 5 mm. inside diameter ($\frac{1}{6}$ to $\frac{1}{5}$ inch) with a sharp cutting-edge and prominent spiral threads to draw the tool into the tree by twisting, as with an auger. Near the cutting-edge is the largest outside diameter of the tube, about half an inch. A tubular cross-

piece handle, which at the same time serves as carrying-case for the cutting-tube, gives a strong purchase in turning the borer. When the tree is bored as far as desired or practicable, a long, fine wedge is thrust into the cutting-tube from the open end outside to hold the core tightly in the cutting-tube while the borer is screwed out from the tree. The first turn, of course, breaks the core away from the tree and the core may be pulled out intact by the wedge. A difficulty with this tool is the fact that in soft and watersoaked wood the outer and softer layers are sometimes compressed and twisted. This is usually negligible, but on one occasion in a dead sequoia the water-soaked wood wedged in the borer so firmly that it had to be removed by boring another tree and thus pushing out the wedged fragments (boring in fallen sequoia at 215 feet from base of root, shown in part in figs. 1 and 2).

Core mounting—The cores usually come out intact, but gluing pieces together is so satisfactory that breakage is no drawback. The core is at once numbered in pencil every inch or two of its length, so that its pieces may be identified if it breaks. It is then put in a paper bag long enough to hold it and a full record made on the outside of the bag. Other numbered cores and their records are added in the same bag, as they help to keep each other from breaking.

These cores are mounted on half-round strips of wood 12 inches long and ¾ inch wide. A shallow saw-cut is made lengthwise at the rounded top, and this cut is rounded with a small round file so that the core will lie snugly in it. It is then glued with the bark end to the right and about 1 inch from the end of the mount. The number is placed at once on the mount at that end. In gluing, the vertical grain of the tree is turned over into a horizontal position. This gives a chance for just the right stroke with the razor blade in "shaving" the surface so that the rings are brought out into the greatest prominence. Identification and dating notes are placed on the wooden mount. The various groups of these mounted specimens are tied in bundles and filed in drawers of the proper width and depth. Such samples resist very rough handling, last indefinitely in this form, and are always ready for further study.

Mr. Duncan Dunning, of the Forest Service office at San Francisco, has made a temporary clamp of great convenience, in which the core may be held while measures of its rings are made. Considering the vast number of cores used by the Forest Service and the ease of replacing lost or injured specimens, this temporary mounting is extremely valuable.

Borer extension—The 12-inch borer is the one commonly used, giving a practical 10-inch core. A 10-inch borer was first tried and a 14-inch has been under examination, but seems too heavy. Very long

borers for greater depth in the tree will probably have to be made in single pieces of tubing.

The tubular borer—This borer was designed especially for the dried and sometimes very hard logs in the prehistoric ruins. It will work on pine trees and junipers. It gives a core 1 inch in diameter, which means a better chance of finding obscure rings than in the increment-borer cores. The borer is a 1-inch steel tube with small sawteeth at one end and a projection at the other for insertion in a common brace. Collections to date include some 30 or 40 very valuable cores made with this instrument. In actual operation the core has been broken off and drawn out about every 3 inches in order to help get rid of sawdust. This extraction is done by a ¼-inch steel rod with a wedge at one end for breaking the core off and a screw at the other end to catch the core fragment and draw it out.

There are two chief problems with a borer of this sort—sawdust and the labor in pressing the borer into the tree or log. For the former a ½-inch auger hole carried below the borer hole and a little in advance has been used advantageously, but frequent breaking of the core is more certain. For the latter a chain-drill attachment was tried unsuccessfully, as it cracked the borer. An auger guide for limited depths is working extremely well in some cases. This guide is a hollow cylinder 4 inches long and 2 inches diameter, with thick walls. Lengthwise down these walls ¼-inch holes are placed fairly close to each other. This guide is screwed to the tree or log with the guide-holes pointing toward the center of the tree. Then a small auger bores into the tree through the holes in succession. The guide is then removed and the tubular borer quickly frees the core. In this arrangement the auger holes take care of the sawdust and the auger itself needs no pressure for forcing it into the wood. The core is not so presentable in appearance, but is easily rounded to a desirable form. This makes a very good form for use on prehistoric beams, but does not solve the problem of deep boring in living trees. A device using the principle of the chain-drill attachment is now under test. There is no doubt that a suitable depth borer can be developed. An effective length of 28 or 30 inches would be enough for the yellow pines. A borer to go 12 feet into big sequoias would probably have to be designed for use with an engine or motor. One would have to be sure beforehand that living trees would supply data worth the trouble.

Injury to living trees—It has been an invariable custom to plug the holes made in living trees so as to keep out any possible infection. This is easily done with a small branch from the same tree, cutting the bark entirely away, so that only healthy sapwood goes into the hole. This amounts to grafting a young branch onto the trunk. Even without this precaution it is not probable that any harm results, as the holes quickly fill with sap or pitch.

Razor-blade holder—In giving a final superb finish to the wood surface, nothing has been found to replace the razor-blade. Files, emery cloth, and scrapers always leave the edges of the wood cells in a ragged state. This may be overcome to some extent with kerosene, oil, or furniture polish, but after clean cutting with a sharp razor-blade the oil finish is far superior. Also, in decayed or burnt wood, after treatment with paraffin, the razor leaves a surface which will permit adequate magnification. Different forms of mounts could easily be made, but a round steel handle split down an inch with a hack-saw and a good screw to draw the split ends together serves as a very convenient mount for the safety-razor blade.

Paraffin treatment—Soft or mealy wood or charcoal is rendered workable by a treatment with paraffin dissolved in gasoline or benzine. This solution should be applied copiously, so that it may enter deeply before it dries. Putting the whole specimen into a jar containing the solution has been found very satisfactory where practicable. Boiling a frail specimen in paraffin is an excellent method of preservation to apply while out in the field.

MEASURING INSTRUMENTS

EARLY FORMS

Ruler—As would be expected, the first measures were made by readings from a steel ruler on edge against the wood. These measures were all made by the writer and were subject to the errors of estimating tenths of a millimeter, but in coarse rings such errors play very little part.

Cathetometer method—This method was worked out for the very long sequoia records and is still regarded as the standard method. It was described in Volume I and need not be repeated here.

PLOTTING MICROMETER

It seemed possible to save a large amount of time by some method of plotting direct from the wood and a special instrument has been designed and constructed for the purpose.

General plan—In general plan the instrument has a fairly inexpensive screw, 6 inches long by about 1 cm. in diameter, with threads having a pitch of 1 mm. A knurled head and a graduated head are attached at the right end for turning and for special reading if desired, but the graduations have not been used (see Plate 5).

The nut on this screw, by a single point of contact, moves a carriage supported on a separate track. The carriage has two upright pieces, between which a small telescope swings on a horizontal longitudinal axis. The left end of the main screw opposite the graduated head has a knurled head which is removable. Below this head, but not in contact,

is a similar head, also removable. The latter is attached to a small drum with spiral thread about it, in which works a catgut string. Between these two knurled heads, but not touching them, is an aluminum disk on the end of an arm, so made that by pressure on a lever the disk comes into contact with both these knurled heads and thus transmits the motion from one to the other and so from the main screw to the catgut string. Several pairs of these knurled heads of different relative sizes are supplied, so that motion in the catgut will be 20, 40, or 100 times the motion of the carriage and telescope. By this means change may be made in the vertical scale of the plot.

Below the main screw and parallel to it is the plotting cylinder. This is so arranged that the same lever-arm that brings contact between the knurled heads moves this cylinder 2 mm. in rotation, measured on the surface of the record paper. The ends of the catgut string pass over rollers and extend parallel to the recording cylinder, and after one end turns back on a small wheel the two ends meet and are attached to the pen carriage, which travels on its own track parallel to the recording cylinder. Thus, when the lever-arm is pressed and the micrometer screw moves the telescope thread across a ring, from one sharp outer edge to the next, the pen draws a line in proportion transversely on the record sheet. The release of the lever-arm at the left moves the cylinder, and the pen is restored to zero position. Thus a columnar plot, here called "auto-plot", is made by setting on one ring after another.

Accuracy—The rapidity and mechanical accuracy of this instrument are high. The graduations of a steel ruler were measured with a very small percentage of error; that is, the accuracy is greater than the accuracy of setting on a ring.

Advantages—The instrument saves much time, because it makes automatically the plotted records which in the cathetometer method were plotted from the readings. These automatic records are called auto-plots. The distance of the wood from the telescope does not have to be fixed. In fact, I have measured rings in wood lying in glass cases by placing the instrument on the outside of the case. The records are in a convenient form and may be very long. They are made on coördinate paper to definite scale, so that values may be read off from the plots for use in tabulation. The plot is also ready at once for a standardizing line, such as will be discussed below.

Disadvantages—While the rapidity and accuracy of this method exceed any other, its disadvantage lies in the difficulty of checking and correcting the work after it is done. Coarse rings are readily handled by inexperienced helpers, but the fine ones under 0.5 millimeter are subject to mistakes. This is usually a question of identification, but the difficulty in checking work immediately after it is done (without

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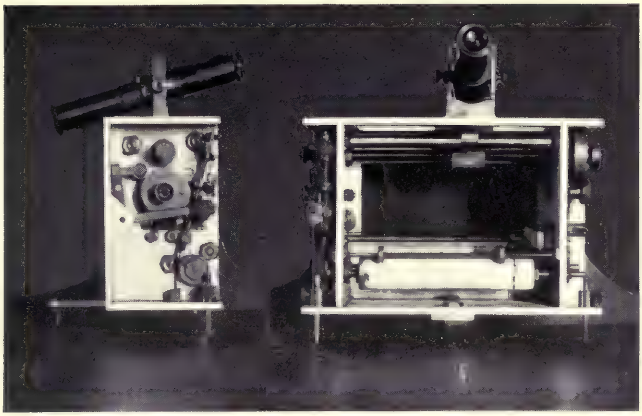
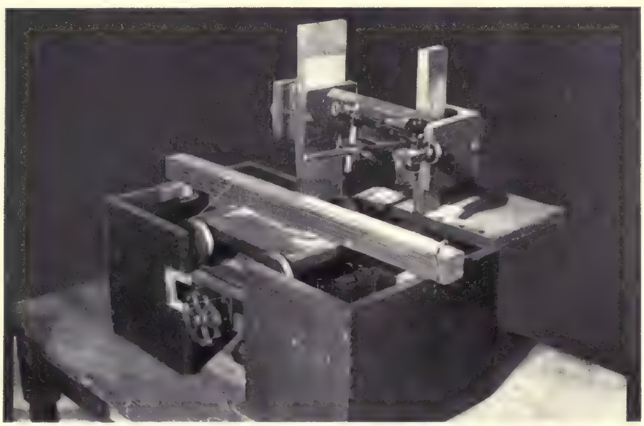
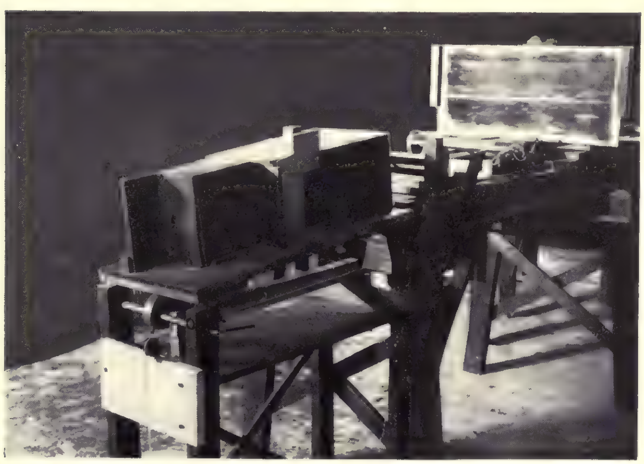


A. Plotting micrometer



B. Longitudinal plotter



C. White cyclograph

doing it completely a second time) is great, and so these errors of identity are not discovered until a careful revision is made by the writer. All this refers, of course, to the measurement of records carefully dated beforehand.

Measuring directions—The best plan for preventing errors in measuring is a written set of measuring directions, telling where to begin and end, what rings, if any, to omit, which are small or microscopic or absent, and where dangerous doubles occur. When a radial sample is specially illuminated during measuring in order to see the rings well in a telescope, marks and directions on the sample may easily be overlooked, but a separate list on a paper at the side can be followed with greater success.

Other applications—Extensive experience with the ordinary filar micrometer in astronomical work led to a design of this instrument which could be used on a telescope for the repeated measurement of the same distance, such as planetary diameters, separation of double stars, and so forth. The box of the plotter was arranged to receive on one side a bushing adapted to the slide-tube of a big telescope and on the other a positive eyepiece. Close to the eyepiece is a plate carrying a stationary thread, while another plate attached to the carriage has the movable thread. The latter is first placed on the left side of the planetary disk and the stationary thread on the right. Then the lever-arm above described is pressed and the movable thread carried to the right until it reaches the right edge of the disk when the other is at the left edge. Thus the double diameter is measured. This may be repeated as many times as desired before looking at the record. A thread stretched along the tops of the columns will give the mean value. This same method can be used in the measurement of average seed diameters under the microscope or the sizes of grains of sand or other objects under special study.

LONGITUDINAL PLOTTER

The measuring instruments so far described all require accurate dating beforehand, for corrections are hard to enter after the ordinary transverse plot has once been made. It happened that considerable material came to the laboratory with groups of very small rings which I did not have time to date, but at a time when there was available the help of an assistant. It was therefore desirable for him to put on a ring-count and make measures which I could correct at my leisure. This was accomplished by the longitudinal plotter (Plate 5, *B*). It simply reproduces the spacings which exist on the wood on a large scale that can be varied to suit the needs of the rings. It reproduces very rapidly and two independent records are placed side by side on the long paper tape such as is used in adding machines. This is called the longitudinal plot, or more briefly, the "long-plot." The

instrument consists simply of a slow-moving carriage on which lies the wood sample and a fast-moving drum upon which hangs the recording tape. These are connected by gearing which normally permits the surface of the drum to move 12 times as fast as the carriage. A pair of gears may be removed and another pair substituted, giving different ratios, so that the range of magnification is from about 4 to about 34 times. In this way a convenient size is entered on the recording tape and the record becomes partially standardized. The motion of the carriage and specimen is watched through a small stationary telescope placed a few inches above and focussed upon the rings and the motion of the drum is recorded on the tape by a pencil line drawn across it against a fixed wire.

Accuracy—On the whole, an inexperienced assistant can handle this plotter better than any other form of measuring instrument. The duplicate records side by side check each other nicely. It is still subject to errors of identification, but a large quantity of dated specimens have gone through this process with good success. It is doubtful if the settings have been quite as accurate as in the auto-plot, but they are still as good as the sharpness of the rings permits.

Graph and table—A sheet of coördinate paper is marked with dates and then each ordinate is entered simply as the sum of the lengths of that year in the two adjacent longitudinal plots. This gives an ordinary graph on which a standardizing line may be drawn, as described below. Suitable ring values for entering in a group table are then read off directly from the graph.

CLERICAL OPERATIONS

STANDARDIZING

Need of equalizing trees—The groups of trees used in this study represent different regions. Therefore, the individuals of each group were selected to represent a considerable area rather than a localized spot. Hence the individuals differ in rate of growth. What we want in an average of a group is the common character which has come from climatic variation. In the tables in Volume I a simple average was used, as that was the easiest process and commonly used in scientific reports. But it is perfectly evident that a straight average does not represent an average of the common character, because in ordinary averaging the big rings in quick-growing trees dominate and variations in the slow-growing trees are practically lost. Logarithmic averaging has been considered; for example, multiplying the values from the different trees together and extracting the root corresponding to the number of trees used. But that is a long and expensive process, and it renders serious the occasional microscopic or omitted ring in very slow growing trees. The effect in such cases would be greatly over-

done. So the practical method of standardizing or equalizing trees, which has been used extensively for actual curve production (commonly modified as in the next paragraph), is to divide individual values by the mean value of the tree, so that the annual values of each tree will enter the group table as percentage departures from its own mean. Simple averages are then taken for each year in the group. This avoids some of the exaggerated effect of extreme departures. It places all the trees on an equality, but does not place all departures on an equality. It is averaging by weight, in which the weight is inversely proportional to the mean growth of the tree.

Age correction—Young trees have to develop the trunk rapidly in order to stand the strain of wind and snow. Hence the early rings are larger and somewhat less sensitive to climatic effects. When the tree curve is plotted, it usually rises at the early end, sometimes very rapidly. A reduction to percentage departures does not correct this. One can correct it by getting percentage departures from a type curve developed mathematically, as Huntington did (1914), but it can be done far more rapidly and with sufficient accuracy by drawing a curved or broken standardizing line on the individual plot and getting the percentage departures from this line. Such a line is usually straight and horizontal for a large part of the record and slants upward at the early end. A curve is more accurate than a broken line, but there is little real difference and the broken line is more easily described if it is necessary to state its position in words.

Other corrections—Huntington used a "flaring" correction for the increased measured width of outer rings near the base of the big trees, where the spread of the root system is felt and a horizontal measurement is not perpendicular to the rings. Evidently, in drawing a standardizing line this can be taken care of. It is evident that in studies of cycles not exceeding half a century or so in length the flaring effect is negligible. But in estimates of very long periods or of secular values, this effect must be nicely gauged.

It is much the same with his "longevity" effect. This effect simply recognizes that a slow-growing tree has a different normal age-curve from a quick-growing tree. The slow grower more quickly reaches the normal slow growth. This, too, is important in getting early absolute ring values, but plays little part in studies of periodic variation.

Comment on standardizing—It is felt that standardizing serves two purposes: first, correction for age, injury and flare, and second, it compensates for few numbers in a group, so that 5 or 10 trees will give practically the same results as 25 or 100. It is not thought important to use it if the number of trees used in a group average is over 15 and the age variations are small.

Averaging—The sums are usually made on an adding machine and the divisions by slide-rule. Once or twice an average by weight has been made. If some character is recognized that makes the record in one tree better than that in another, a suitable weight can be included in the standardizing process by placing the standardizing line at a different ordinate. In the table the same effect has been produced by repeating the same tree in two or more lines, giving it double or more weight.

CYCLE PLOTS

Uses of tree-growth curves—There are three main purposes in producing tree-record curves and certain advantageous characters vary in these uses. They follow.

Cross-identification—Curves for this purpose must display certain special characters like single small rings or drought groups of small rings, which from their extreme and unusual character are likely to extend over a considerable district. The single small deficient ring is the best characteristic to use in dating. Good years seem to spread their effects over a longer period of time and are not definite.

Skeleton plot—In consequence, a special "skeleton" curve has sometimes been successfully used in cross-dating. Such curve is a long, narrow strip of coördinate paper, dated or numbered as usual and showing only the dates of very small microscopic or absent rings, which are indicated by vertical lines whose conspicuousness is proportional to the deficiency of the rings. No other rings are represented in these plots. Two of these skeleton curves from different trees, one known and the other unknown as to date, can be moved slowly past each other until similarity of spacing discloses identity in dates.

Plotting climatic curves—By comparison of growth-curves the climatic origin of many tree variations is established; hence these curves need to show all the individual years. The scale should not be too great, as then it is difficult to compare two plots. Therefore, the ordinary form, consisting of points connected by straight lines, made on such a scale that slopes dominate, is the more convenient. It has been found most advantageous to use coördinate paper whose smallest divisions are 2 mm. and whose major lines are spaced at 5 (not 10) of these small divisions. On this paper the smallest horizontal division commonly represents one year and rather commonly 2 vertical centimeters represent 1 mm. of tree-growth.

Cycle plots—These are the curves arranged specially for studying the cycles. At first it was thought that the usual unsmoothed plots just described were well adapted for this purpose, but it was noticed that in searching out some cycle with the periodograph, or cyclograph as it will usually be called in this volume, several possible settings

were obtained differing by exactly one year, such as 17.1, 18.1, and 19.1 years. This, of course, arose from retaining annual points in the plot and in the cycle one was apt to select some multiple of unity, that is, simply a whole number or very close to it, instead of an actual fractional value.

Smoothing—Accordingly, some form of smoothing is now always used, and the Bloxam formula, which I have sometimes called Hann's formula, is generally accepted. But there are several variations of this process.

Numerical Hann—The first is the simple application of the Hann or Bloxam formula, in which three successive (overlapping) values are merged into a substitute for the middle one by averaging the three, with double weight given to the second. It is this double weight applied to the original whose substitute is desired that differentiates this formula from a running mean of three. The place of this emphasis will be referred to below. This process may be done on a set of tabulated values by two successive sets of intermediates, as explained in a previous volume.

Geometric Hann—This is the same process, done graphically on a curve already plotted, by taking each three successive points as the corners of a triangle. Consider that the first and third points form the base. From the center of the base, one-third of the way to the middle point will be the running mean of three, while one-half of the way from the base to the middle point will be the weighted mean or the "Hanned" value. This forms in practice a very easy way of smoothing a curve and has been very largely used in a slightly abbreviated form which I have called the graphic Hann.

Graphic Hann—The plotting paper used in the cyclograph needs to be 4 inches wide by some 45 inches long, fairly opaque, and with parts of the curve cut out so that light may pass through. All this is best done on rough brown paper cut in strips of the proper size. The present process, therefore, is to plot the tabular averages directly on a long strip of coördinate paper, using a rather large vertical scale, so that variations will generally be an inch or two high. This strip is placed upon the heavy strip of brown paper with carbon paper between and a blunted needle or pointer is passed slowly along the plotted curve, touching the points which by eye estimation and occasional measure should constitute the geometric Hann. Century dates at the same time are touched, so that the curve thus transferred becomes a satisfactory working smoothed plot of the standardized group average. This is called the graphic Hann and can be done quickly and accurately. This process of smoothing has a perfectly definite ideal to look to in case of doubt and I believe is almost entirely free

from erratic estimations, on account of which ordinary eye-smoothing may be criticized. The graphic Hann thus formed is the basis of the cycle plot whose process of formation will be continued below.

Emphasis point—In the Hanning process just described the emphasis is laid on the middle point of the three. This has been used in so large a part of this curve-production that it is here given preference. But there is some question about its use when conservation is considered, for it intimates a reversed or negative conservation in the last year of the three (see p. 101). If rainfall is retroactive, that is, if it affects rings already formed, the tree records ought to show some anticipation of abrupt changes in the rainfall. On the other hand, placing the emphasis on the last of the three years used amounts to admitting a conservation of moisture from the two preceding years. On the whole, it is felt that middle-point emphasis has given more satisfactory curves than emphasis on the final year.

Cutting-line—The cycle plot has the maxima of the curve cut out so that light may pass through. The curve produced by the graphic Hann forms the upper side of this area to be cut, but the position of the base of the cut area has proved very important in the successful use of the analyzing instrument and therefore I have always had the curves at that stage returned to me to have the base or "cutting-line" marked. In any analysis the variations of the curve are the important features; hence, if the cutting-line is placed along the X-axis or the true base of the curve, the variations are reduced to very small percentages of the total light coming through and can not be seen. Even when the cutting-line is placed at the lower minima, the light is so abundant that it is very hard to get the variations visually or photographically. After extensive trials of every sort of height for this line, I have come to the general plan of sacrificing about one-third of the vertical height at the bottom of the minima and marking a long, sweeping line nearly straight, but not entirely so, as that brings the best display of variations within the range of the instrument and has not been found to affect the results.

The range of the instrument as now in use is confined to periods between 6 and 32 years (see "Recent changes," below). The cutting-line, therefore, to show these best, may be curved so as to cut out or reduce longer periods. They, however, are taken care of by plotting at a reduced scale. This has been done extensively with long sequence of rings extending 500 years or more.

Cutting the plots—The final work on the cycle plots is cutting out the maxima, which, of course, is a simple matter usually done with a razor blade.

THE CYCLOGRAPH (PERIODOGRAPH)

COMPARISON OF ANALYZING METHODS

This study of tree-rings has become a study of the history of climatic cycles. The technique so far described covers the production of tree-record curves ready for analysis by a special instrument designed for the purpose and called a cyclograph. The number of curves to be analyzed is so great and the data sought so complex that this work would hardly have been done by a mathematical process. Harmonic analysis in its mathematical form has been so successful in numberless studies that many investigators have come to regard it as essential. A very clever illustration of its power is Miller's reduction of a facial contour to a mathematical formula which when plotted reproduces the contour. Of course, this was done by combining a long descending scale of period lengths with the distribution of emphasis (amplitudes) on just the right ones. But after this beautiful illustration we must not forget that this form of contour analysis has nothing to do with the physical causes of the contour, nor does it help us in predicting other contours. It is like a photographic plate: it merely places that one on record.

So in the case of the sunspot cycle, we can reproduce the known historic sunspot curve by 20 harmonics with different amplitudes, but when done we can not insist that the sunspot variation is really built of those harmonics. So also with climatic cycles, we do not know yet how far their physical causes are harmonic, and therefore the expression of climatic variations in a Fourier series begs the question. Evidence in a later chapter suggests distinctly that climatic cycles are simple fractions rather than harmonics of a fundamental. So the photometric process described below is permissible. Add to this its rapidity, which is of the order of 50 times as great as the mathematical process, while its flexibility belongs to a different class altogether. The mathematical process is not flexible at all in the sense this is. The process here used bears somewhat the relation to the mathematical process that calculus does to algebra; it is differential. In applying a cycle to a long sequence of values, one sees at once at every point how far the values depart from the cycle. A varying cycle enters simply as a curved line, while a fixed period appears as a straight one. Two interfering cycles, forming a false third, enter as two straight lines or bands intersecting and their intersections form the third. In this process the operator not merely gets an analysis of the whole sequence of values, but of every possible fraction of them, an accomplishment of the highest difficulty in any mathematical solution. For example, Schuster analyzed the sunspot variations since 1750, dividing the whole series into two parts, and missed the points of discontinuity near 1788, 1830, and so forth. These discontinuous points are the most conspicuous features of the cyclograph analysis here used.

On the other hand, some will object, and correctly, that the cyclograph process does not give in figures the harmonic constants. Two points answer this; the first is that the cycle must first be caught out of a very complex combination of variables, and second, when the cycle is known it is easy to get its constants by mathematics, if desired (or by photometric means from a cyclogram).

PRINCIPLE OF THE CYCLOGRAPH

The earlier forms of the instrument have been described in the previous volume and need no repetition. The principle also was explained, and is briefly outlined here only as an introduction to the present form. The maxima of the curve to be analyzed are cut out, so that light passes through in proportion to the ordinates, as already described under the title Cycle plots. The horizontal spacing of the maxima of light is emphasized if the cutting-line is high, leaving the extreme minima without illumination. Now let us imagine a plot of this sort consisting of a series of evident maxima which seem to be equally spaced (as in the sunspot curve), and we wish to find if they are strictly periodic. We illuminate the curve from the back, place a lens at some distance before it, find the image cast by the lens, and compare the white spots in the image with an adjacent series of dots which we have placed on exactly equal spaces. If the dots are closer than the maxima, the lens is carried farther from the curve, reducing the separation of the focal images until they coincide in the average with the equally spaced dots. Then we see clearly that the maxima largely match the dots but in certain places; let us say, they draw away. These departures let us call differentials.

So long as differentials take place in their own line (like the longitudinal vibrations of sound) it is hard to estimate them, but if these differentials can be turned out perpendicular to the line of the curve, that is, made transverse (like light-waves), it is very easy to see and measure them. This is very easily done by extending both maxima and dots indefinitely in the transverse direction but at a small angle to each other. This effect is produced on the curve image by adding a cylindrical lens which converts each maximum of the focal image into a vertical band. The same effect is produced on the dots by inserting in their place a series of equally spaced nearly vertical opaque parallel lines. To give these lines accurately, a ruled screen such as that used in photo-engraving is placed at the focus of the lens and the row of vertical bands comes through the slightly inclined transparent spaces between the lines. This produces an interference which should be seen to be appreciated. If the maxima are equally spaced, they come through as straight horizontal rows of white spots, but where differentials occur, the spots are displaced above or below the straight line. Departures from a perfect period are at once recognized,

because longitudinal displacement has been turned to transverse, thus making a departure from a straight line which is at once apparent.

Invention and name—This pattern was first designed by the writer in 1913 and published in 1914 under the name of a multiple plot.* Its automatic production by this method of interference was worked out that same year and published in 1915. It was then called a differential pattern and was used as the basis from which to photograph a true periodogram, as described in Volume I. In the present volume, however, the periodogram is omitted, since there has been very little use for it in comparison with the pattern. With the construction of small portable instruments for producing this pattern, the word cycloscope has come into use as their name. In a corresponding way the large analyzing instrument with its photographic attachment, constructed with the fund given by Mr. Clarence G. White, of Redlands, California, has come to be called the White cyclograph; the photographs obtained by it are here called cyclograms.

THE WHITE CYCLOGRAPH

During the building of the previous instrument in 1918 the thought in mind was the production of a periodogram as suggested by Schuster. But with the extensive use of that instrument it became apparent that the differential pattern or cyclogram designed as merely one stage in the process was far more important than the periodogram. The periodogram merely produces the kind of results that come from a mathematical process; the cyclogram contains far more than that.

At the same time, the long track of the periodograph compelled the observer to walk indefinitely back and forth in an awkward position. So it was first intended to arrange a mechanism to eliminate this walking, but as it took form the lessening importance of the periodogram was realized and the attachment for producing it was omitted. It could, however, be added at any time if thought worth while.

Illuminator—The arrangement for mounting the cycle plot so that light comes through in the proper way is called the illuminator. For a long time daylight was used, thrown onto the curve in a darkened room by a slant mirror at the base of a window. Then thin white tracing-paper replaced the mirror and gave a broad area for comparing different curves. One curve some 40 inches long and 4 wide was insufficient and a second could be put above it. But for close comparison of many curves for dating purposes a light frame sliding vertically was arranged to carry 10 curves at once. This frame was suspended by a cord over a pulley and analysis could pass from one curve to another at any desired speed.

*It appears to be identical with Clayton's "phasogram" in World Weather, page 379. The multiple-plot method of making a periodogram was described to him in conversation in the summer of 1913, and he remarked, "Well, you might expect an astronomer to work out an optical method."

When it became necessary to move the instrument to a locality where a suitable window was not available, 10 electric lights in a row were used, with a mirror behind and several thicknesses of ground glass between the lights and the curve to spread the light evenly. This is mounted on a table or stand, but it is planned to combine all this equipment with an attachment which will permit the curve to turn on its center through a horizontal angle, for by this means the range of analysis can be greatly extended beyond the previous 32 years. This slanting of the curve can only be done when it is at maximum distance from the lens, for the two ends would come in at obviously different scales. To do this the whole illuminator will have to turn on a central vertical axis.

Track and carriage—The cyclograph track is 18 feet long (see Plate 5, *C*), made of light beams well braced, carrying cross-pieces, notched at each end to hold two lengths of ½-inch round steel shafting which serve as rails. The rails are 18 inches apart. The carriage has two grooved wheels on one side to run on one rail and hold the alignment. On the other side is a single flat wheel.* The carriage holds a vertical mirror 30 inches wide and 15 inches high, facing the illuminator and the analyzing-box. Seen from the mirror, the former appears slightly, but directly, above the latter. The carriage is moved by a cord passing over a small wheel at the outer end and a drum with small spiral groove about it at the observer's end. This drum has a handle within reach of the observer as he sits at the side of the analyzing camera.

Scale—The scale runs along the side of the track and the carriage has a mirror and light so arranged that the observer may see the lighted scale at any position of the carriage. A small telescope is provided for reading the distant positions. The graduation is put on from standardized curves, which are always kept on hand and measured and tried from time to time. In dry climates all curves shrink perceptibly and thus scales have to be watched.

Range extension—The actual length of the track covers a range of periods from 5 to 18 years. In order to increase this to 32 years, two mirrors have been used, one fixed high above the track, throwing a beam back toward the analyzing-box, and the other at the front of the box in this beam, so placed that when it is raised in position it catches the beam from the first extra mirror and sends it to the mirror on the carriage, at the same time cutting off the direct light from the curve to the carriage. This nearly doubles the maximum path of the light from the curve to the analyzing-box and increases the range of periods tested from 18 years to over 32 years.

Camera inclination—One bit of awkwardness remains in this design, namely, the necessary change of slant of the camera-box when

* This same carriage was used on September 10, 1923, in photographing the total solar eclipse from the University of Arizona station at Port Libertad, Sonora, Mexico, with a 40-foot horizontal telescope.

the movable mirror is changed in distance. In order to get the reflection from the mirror properly placed, the box has to have its plate end lowered when the mirror comes near.

Cyclograph camera—By the track-and-mirror arrangement, above described, the observer can stay at one point while the moving mirror changes the effective distance between the curve and the lens, and by changing the size of the focal image brings into view all the range of periods of which the instrument is capable.

Lens.—The lens is a Tessar II B of 6 inches focus and about $\frac{3}{4}$-inch aperture, with a negative cylindrical simple lens of -6 inches focus with horizontal axis, so that in the vertical direction it neutralizes the action of the main lens. Without the cylinder there is an ordinary image at 6 inches. With the cylinder all the horizontal spacing comes in as before, but there is no vertical focussing; consequently, each maximum in the curve appears in the image as a vertical band whose intensity is proportional to the height of the maximum.

Automatic focus—The lens is mounted as in previous instruments inside and on the base of a suspended parallelogram with hinges at each angle. The length of the parallelogram extends along the axis of the instrument, in line with the track. This permits a focussing motion of the lens in its axial line. From the front of the parallelogram a lever-arm extends downward and is attached by an adjusting-screw to a horizontal rod passing forward toward the axis of the drum which moves the mirror-carriage. A cross-piece on the rod bears against a brass spiral mounted near the axis of the drum and turning with it. This spiral is so arranged that as the drum turns, the position of the lens changes and the focus is maintained in a fixed plane.

Analyzing-plate—The analyzing-plate is fixed at the focus of the lens in a brass mounting attached to the back of this front compartment of the analyzing-box. The mounting has been elaborate enough to test many details and is rather more complete than ordinarily needed. On the fixed plate is a circular brass plate which can be rotated through 45° against a graduation in degrees. A rectangle 1 inch high and 2 inches long is cut through the circular plate, and on this rectangle is mounted the analyzing-plate, covering a little more than the rectangle. The ruled lines of the plate are vertical, that is, parallel to the short side of the rectangle. In normal position the circle is clamped so that the lines are inclined 12° from the vertical, and therefore 12° from the vertical bands in the image.

The plate itself is made of two screens accurately ruled 50 lines to the inch, face to face, one fixed and the other with a slight motion controlled by a screw. The purpose of this is to change the relative size of the transparent part of the ruling without changing the distance from center to center of the lines. In each screen the opaque ruling is equal in width to the transparent space between. So by moving

one screen slightly across the other, the transparent part can be changed from zero up to 0.01 inch. The width found advantageous is 0.004 inch or two-tenths of the spacing of the lines.

Visual compartment—From the analyzing-plate the light passes into the middle or visual compartment through the condensing-lenses. These are two 6-inch positive cylindrical lenses with vertical axis, so that the eye placed 6 inches away may receive all the light from the plate and see its whole area. It is more convenient to have the observer at the side than at the end, where he may interfere with the light coming from the curve beyond, so back of the condensers is a vertical mirror on a hinged support. When the support is pulled forward, it takes a position at 45° and throws the beam out at the side through a small lens and to the eye. The lens puts the image slightly out of focus to the eye, as in such condition the eye recognizes alignments of blotches better.

Photographic compartment—When the mirror-support is thrown back out of the way, the beam goes straight on to a triple lens of 3 inches focus, which reproduces the analyzing pattern on a ground glass in the third and last compartment. This last compartment is held separate on a clamp by which the ground glass may be brought to the most advantageous focus. A plate-holder fits in place of the glass and may occupy three slightly different positions, so that three exposures can be made on the same plate.

Recent changes—The above description gives the form of the instrument used in the cycle analyses in this volume. But since writing this chapter added floor-space has made it possible to lengthen the track to 40 feet. With this the two extra mirrors have been removed, together with the automatic focussing device and scale illumination, and a small convenient scale is now located directly in front of the observer.

CYCLOSCOPE

A small portable analyzer has been constructed for exhibit purposes, but fully equal to real analyzing work. It consists of a small illuminator with a long electric light inclosed and cord to be attached to a wall-socket. Curves 10 inches long may be placed in this. The analyzing part is a box 12 inches long and 4 inches square, with top which opens on a hinge. It carries a convex spherical and a cylindrical lens at the front, with a little chance to focus by hand; then a simple analyzing-plate fixed at the proper inclination; then condensing-lenses and an eye-lens. One looks through it toward the illuminated curve and walks nearer or farther and watches the changing pattern. When a cycle is indicated by proper horizontal alignment of spots in the analyzing pattern, its value may be found by a simple formula after measuring the distance from the lens to the illuminated curve.

VI. TREE RECORDS: LENGTH

The first definite purpose in making the collections here described was the extension and improvement of the 3,000-year sequoia records presented in the previous volume. This was followed by a similar plan in regard to the yellow pine as soon as certain probabilities of extension were realized. The present chapter deals with these attempts. As the number of specimens grew and material came from many sources, the study of local and continental topographic effects took shape and has become a central theme of this volume, as indicated in the succeeding chapters (VII and VIII). Finally, large quantities of early historic, prehistoric, and geologic material came to the laboratory and the problem was presented of reconstructing, in part at least, the climates of past ages by such indications as could be found in tree-rings. Hence arose the thought of collecting and formulating climatic indicators in trees (VIII). All this is of fundamental importance in the continued investigation of climatic cycles and tree-growth (IX).

OLD SEQUOIA RECORDS

THIRD SEQUOIA TRIP, 1919

The trip to the groves near General Grant Park in July 1919 was made for the purpose of determining the status of a certain ring called 1580A, which was in doubt because it had appeared in less than half of the 23 specimens at that time in hand. It was also planned to make a topographic study of the influence of the immediate environment, especially ground-water, on ring-growth. After a trip to Wigger's, just south of the Park, to see an immense stump, and after an examination of the General Grant tree to estimate its age, I went to Hume and on the 12th accompanied a guide to the farthest parts of Camp 6, where Nos. 1 to 5 had been collected, and selected new specimens for cutting. The next day, with burros and a helper, camp was made at the mouth of Redwood Basin, near the spring. With no one to help, the radial pieces cut here the next morning were not on the scale previously obtained. Instead of being 6 or 8 inches wide and deep, they were about an inch in those dimensions. This meant their breaking into many small pieces, which were immediately put into small marked bags. The new specimens supplemented the 13 already obtained in that district and gave opportunity of testing more thoroughly the relation of sequoia growth to ground-water, which will be discussed in a later chapter.

The next day we cut a new radial from D–12 in Indian Basin, which had previously failed to give a satisfactory dating on account

of badly compressed rings near the outside. A good radius was selected and a conspicuous ring was traced across from the new radius to the old and its position on the old accurately determined. It proved very easy to extend the dating on the new radius back to this ring, and with this good start the entire dating of this tree proved very satisfactory, in spite of the complacency of its growth.

We returned to the Park and the next day I cut radials 32 to 35 at Converse Hoist. These supplemented the two obtained the year before in that vicinity by going higher up on the ridges for Nos. 32 and 35 and nearer the creek for 33 and 34.

This locality is a very interesting one, because it contains the stump D–21, which had 3,200 rings in it, whose central rings were shown in Plate 1. Very old trees are rare. I have examined many hundreds of stumps, made estimates of their age, and in many cases have counted the rings. There were in these forests many trees over 2,000 years of age, but probably very few over 3,000. Only 3 stumps of this age are known so far. Two estimates of the General Grant tree gave 2,000 and 3,000 years of age, and its true age is thus taken as 2,500 until some better opportunity comes for getting its number of rings. The Centennial stump nearby was estimated to have some 1,800 rings and the large stump with raised center at Wigger's probably is 1,500 years of age.

FOURTH SEQUOIA TRIP, 1924

The fourth sequoia trip in July 1924 had two objectives; first, the improvement of the general sequoia record, and second, the securing of certain indicators needed in the problem of correctly dating large numbers of prehistoric tree-sections from the ancient ruins of the Southwest. Such dating would not only help the archæologist, but at one stroke would also extend the superb yellow-pine climatic record by more than 300 years at least. The general problem of dating unknown tree-records will be taken up at another time. It is sufficient to say here that one way to accomplish such dating is by cross-identification between the pines of the Arizona region and the sequoias of California. This apparently would be easy by comparison of the occasional common deficient years, perhaps eight per century, except that in about one-fourth of such cases the Arizona deficient year occurs one year late. For example, the small sequoia rings for 1846, 1812, 1541, and other years in California come in 1847, 1813, 1542, and so forth, in Arizona. The attempt is, therefore, now being made to discover in the pines or sequoias, or both, some internal signs by which to know just when this difference of one year is to be expected. Hence, in approaching this problem from the sequoia point of view, it seemed best to go to other sequoia groves and see if some indication of this occasional discrepancy could be discovered.

Accordingly, a trip to the northerly Calaveras Grove was made in early July 1924, by stage from Stockton. This grove was the first one discovered and the marble slabs with tree names are reminiscent of the pioneer days. The hotel is picturesquely situated at the edge of the grove and nearby is the Dance Hall mentioned by Mark Twain. This hall is on the stump of the first big tree cut (1853) and the early difficulty in penetrating such immense trunks is apparent, for in this case it was done by large auger-holes made on opposite sides toward a selected diameter. These holes show in the great butt-log still lying close to the hall. This tree was quick-growing and estimated to have some 1,200 or 1,400 rings only. It was probably the one from which a tracing of the whole set of rings was made about 1865.

The road, as it approaches the hotel, formerly passed between the "Sentinels," two fine sequoias, but one had fallen the previous year and a boring in it at some 50 feet from the original ground-level, checked by a similar boring from another fallen tree, gave a perfect start in dating the trees in this grove. This actual dating, however, proved unnecessary, for it was perfectly easy to date all the records obtained by comparison with the known records in the more southerly groves. The trees in this grove are standing and, therefore, it was difficult to get any satisfactory radials. However, a very few old trees had fallen and small pieces were cut from three in inconspicuous places by which the record was carried back some seven centuries. Incidentally, this dating of fallen trees gave excellent data on the durability of sequoia bark and sapwood already referred to.

This grove is small, perhaps one-third of a mile across, and lies in a flattish, slightly depressed area with drainage to the southwest and protected on the other sides by hills and ridges a few hundred feet high. Its elevation is 5,000 feet and the precipitation in this neighborhood is probably near 40 inches, mostly in winter. The ring-growth is very complacent, with deficient rings showing but rarely. The average size is smaller than expected. The easy cross-identification with the tree records in the other groves shows that the entire area of *Sequoia gigantea* in California is essentially a unit in its climatic reaction.

A full day was given to collecting yellow-pine borings in connection with the study of modern tree-records over the whole western area. Trees were selected in an east-and-west line across the grove from the hilltop back of the hotel to the ridge on the east, where the main highway passes and the trail to the South Grove branches off. These pines cross-identify well and are included in the western groups under the abbreviation CVP. Eleven trees comprise this close group, but three more were added at elevations nearly 2,000 feet above sea-level in the vicinity of Murpheys. These three, however, give essentially the same record as those near the grove and are included in the CVP

group. The Calaveras Grove of sequoias is privately owned and these specimens were obtained by courtesy of Mrs. Whitesides, in charge at the hotel.

FIFTH SEQUOIA TRIP, 1925

The dating of the specimens from the Calaveras Grove led to the conclusion that the tree-records there resemble the Arizona pine-tree records less than the sequoias farther south, instead of more. So it only remained to visit the most southerly grove near Springville and secure better material than already collected there. In 1918, two 3,000-year old radials had been secured from the Old Enterprise mill-site. These both cross-identified with trees 50 miles north near the General Grant Park, but while the cross-dating was absolutely reliable, the resemblances were not so close as hoped for and were not equally good in the two trees. No. 23, age 3,100 years and growing near the drainage brook, showed less agreement than No. 22, age 3,000 years, growing near the center of the grove. Accordingly, the trip was made by auto from Pasadena to Springville on August 4, 1925. Mr. Charles A. Elster, of that city, met us and next day took us to his Camp Lookout and sawmill in the pines at an elevation of about 5,000 feet above sea-level. After lunch he drove us up the steep grades, past the old Frazier mill-site of 1885 and the Elster mill-site of 1901, to the Enterprise site of 1898. The Conley mill of 1892 at Brownie Meadow, off the road to the north, was close to D–49, which had been cut by Mr. Elster himself in 1892. Mr. Elster had worked here in the lumber business almost since its beginning and his recollections were of the greatest help. The afternoon was devoted entirely to the selection of suitable stumps for cutting. It seemed advisable to get the very oldest and, if possible, to exceed the previous maximum of 3,200 years (but that hope was disappointed). At the same time it was desired to get a range of younger trees in order to develop an improved system of age corrections.

The next day the cutting of radials began. This was done by two helpers in charge of Mr. P. W. Weirick, of Pasadena, who very kindly assisted me on this trip, thus enabling me to spend the entire time in the selection of specimens. So two days were spent in this way and in securing specimens of pine growth (see p. 88), and on Saturday, the 8th, Mr. Elster took us to Balch's Park to see the marvelous old tree appropriately named Methuselah. That afternoon we returned to Springville and the next day to Pasadena.

On returning to Tucson, several of these long sequoia records were dated, including one of 2,600 years, but it finally seemed best to postpone the complete study of this material to a time when proper attention could be given to old and prehistoric records in connection with climates of the past. Hence, its further discussion will be reserved for another time.

COAST REDWOOD RECORDS

The value of very long and old ring records is so obvious that every effort has been made to discover them. The coast redwood is a very available tree, growing to a great age, but its preference for the coast's even climate and its avoidance of winter snows led many years ago to doubts of its usefulness in these ring and climate studies. Moreover, about 1912 the late Julius Kapteyn did some counting on the rings of the coast redwood in the hope of finding climatic or solar correlations, but was disappointed. At any rate, the possibility of its usefulness deserved a real test and two groups of this species have been collected.

SANTA CRUZ GROUP, 1921

A trip made on February 20, 1921, was arranged through the kind assistance of Mr. R. E. Burton, of the high school in Santa Cruz, who took me out some 15 miles in a northerly direction from that city to a point near Major's Creek, where redwood trees had recently been cut. This location was in the upper part of the low range of coast hills, but on the eastern slopes, so that the drainage was toward the northeast and inland at that point. The first trees selected were at the upper end of a gully, often dry; others were cut in the valley bottom and others on the very steep slopes of a side-wash. The 7 specimens collected there were studied for months and no satisfactory cross-identification was found. Trees 10 feet apart cross-identified and gave apparently good records, but other trees 50 yards away gave a different record which could not be identified with the first. In the outer parts of some good specimens the rings would interlace in a way never noted in the big sequoia; for example, some red rings merged in one direction with the ring next outside and in the opposite direction with the red ring next inside. Dating was therefore hopeless and has not been accomplished to this day. The general age of these trees was not great, probably from 300 to 700 years.

SCOTIA TRIP, 1925

The above negative result was not conclusive, for it might be a characteristic of the locality chosen or of the southern redwoods only. So the long auto trip of June 1925, described later, was directed to the redwood region of northern California. We motored from Grant's Pass, Oregon, to Crescent City, on the extreme northern coast of California, and thence through those wonderful redwood groves to Eureka and Scotia. At Eureka, the center of the redwood-lumber industry, I consulted representatives of the Forest Service and was referred to Mr. Percy J. Brown, whose mill and forests were on or near the main highway to the south. The general area included a square mile or so of bottom land some 30 feet above the level of the Eel River. This land rises very gently toward the hills on the south, but the slope

grows steeper in the outwash-fan from a small canyon entering the hills. Twelve stumps were selected of different sizes and at various scattered points. Of these, three were high up on the ridge forming the east side of the canyon. Here the cutting had been done some years and the young sprouts of redwood from the stumps formed dense and tangled masses which had to be cut away in order to get at the stumps. In the bottom lands below the cutting had been recent, some of the trees having been felled only a few weeks, so there was no difficulty about getting the final dates. The v-cuts were 4 to 6 inches wide and deep and thus were excellent specimens, well selected and in perfect condition. They were prepared and mounted by Mr. Swan Erickson at Tucson under my direction and cross-compared by him and later by me, but no cross-identification was found. Some of the bottom-land specimens seemed to have perfectly clear records, yet with close study the different trees did not agree. It may be that further study will produce some way of using these good specimens, but so far they are not usable in this study of climate and solar activity. This is unfortunate, since many of them carry records over a thousand years in length.

DEFICIENCY OF THE COAST REDWOOD

Though it is true that years ago the theory was entertained that winter snow is important in producing trees that give good climatic records, this failure of the coast redwoods was a surprise. Probably the subsoil water-supply and certain habits of the tree itself increase these nonclimatic variations. The trees get much moisture from the coast fogs, and Mr. W. P. Hoge, of Mount Wilson, tells me that in a fog the trees show some very curious anomalies in their capacity to take moisture from the air. Again, if moisture is in too large a quantity, sunshine would be the controlling factor in growth, though this is not at all likely in the southern groves. But a greater difficulty lies in the way these trees reproduce after fire, which is by sprouts from the base of the mother tree. Hence, these trees when near together are apt to be connected underground. This method of reproduction leads to very erratic growth, as observed by Dr. Emanuel Fritz, of Berkeley. In a letter dated May 15, 1923, he says:

"This section of second-growth redwood is interesting because it shows a large number of rings merging into one and thus on some radii giving an incorrect indication of the age of the tree. In March we cut three-quarters of an acre of second-growth redwood 65 years old and under, and found to our amazement that trees were older at the top than on the stump. Very careful study soon brought to light the fact that we were not counting the rings on corresponding radii. After this discovery we had no further trouble. As you know, redwood sprouts very freely from the stump. As these suckers mature, they crowd out one another and leave but two or three in a clump. Often

the cambium layer is common around the group. We noted that on that side of the tree which faces closely another sprout, there is a dearth of growth-rings. On that side also there is practically no foliage clear up to the tip. The most peculiar thing about this lack of ring formation on one side is the sudden change from the normal to the abnormal."

In another letter soon after, he says:

"The trees cut in this experiment . . . . were many of them sprouts. Two to six sprouts, 15 to 35 inches in diameter at breast height, were found around many mother stumps. This sprout-clump habit makes the trees touch one another at the base (sometimes after 50 years to develop a common, or rather a continuous cambian ring for two or three trees at stump height) and to be separated at the top by 3 to 6 or more feet. Tree No. 90, from which the specimen was cut, was of this class. The crown was all on one side. The most difficult thing to explain in the specimen seems to me to be the reason for the sudden change from normal growth to asymmetry and then a return to the normal."

The coast redwood may some time be used in the study of climate and solar activity, but its interpretation is so complicated that for the present it can not be included in this study of modern and historic trees.

OLD PINE RECORDS

For climatic records involving rainfall as the most important factor, no tree has yet been found superior to the yellow pine of the arid Southwest. It combines a wide range of growth with excellent sensitiveness and a reluctance to drop rings completely in deficient years (as the junipers do). Next to it, perhaps, comes the Douglas fir, which has larger growth with usually greater sensitiveness, so that for the same size of trunk it has fewer rings with over-exaggerated representation of climatic changes. Therefore, extension of climatic records in the pine trees is most desirable.

SEARCH FOR OLD TREES

In the summer of 1919, Flagstaff was visited primarily for the purpose of investigating certain buried pine trees in the recently filled land immediately north of town, which will be described in another place. September 10 was spent in a "University" section, 5 miles south of town, a section which had long been pointed out as having most beautiful pines with clear trunks, suitable for fine lumber. These trees were on nearly level limestone, breaking to lower levels at their south edge and protected to the west by the volcanic bulk of Woody Mountain. There seems to be no special protection from the occasional powerful northeast wind. This region had been cut over recently and it was easy to select the large stumps with fine grain.

Of the 8 radials cut (Fl–33 to 40), 5 had an age of 500 years. Only 2 such trees had been found before. Thus by one day's work a reliable 500-year record was obtained (see Plate 6).

Burnt centers—All this seemed so encouraging that on August 28, 1922, another visit was made to this locality for the purpose of collecting "burnt centers." It had long been hoped that the tree record could be carried back before 1,400 A. D. by finding stumps or logs of earlier origin which in some way had been preserved. For example, a tree blown down by the wind might be buried and thus preserved, or it might have fire injury which would cause the central parts of the stump to fill with pitch and thus withstand weathering. So on this visit the larger burnt stumps were sought and partial radials cut from their centers. Out of 5 so collected, numbers Fl–95 to 99, one was too complacent for dating, 2 began about 1500 and 2 began before 1400 A. D. Of these two, one undoubtedly started by 1350, but the very center had rotted away and no real gain was made. Yet these two were thoroughly filled with pitch and presented records which match in a remarkable manner certain dated beams from the pueblo buildings of the Hopi Indians.

In the summer of 1920 two other 500-year trees were reported to me at about the same time. On June 17 a radial from Fl–41, a 66-inch stump in the northwest corner of Fort Valley, was cut. This very old tree stood at the edge of the flat valley floor, in good soil, near large outcroppings of volcanic rock, on which the Southwestern Forest Experiment Station stands. Mountains protected it to the west, north, and east, but not especially on the southwest and southeast, and southwest winds are sometimes very strong.

On the following day another stump of even larger size was visited near the top of Woody Mountain, 10 miles to the south. This was numbered Fl–42. By courtesy of Mr. T. A. Riordan, president of the Arizona Lumber and Timber Company, a full section of this splendid tree was cut and shipped to Tucson. Each of these 500-year trees was somewhat complacent; in fact, they and the still older tree mentioned below have decidedly less sensitive records than the previous 7 trees of that age. Five of these 7 had come from the university section, some 3 miles east of Woody Mountain, and 2 collected in 1906 had come from about 2 miles west of the same mountain.

A 640-year pine—In early July 1923, Forest Assistant Merker and Forest Examiner M. Westveld discovered a pine stump in the canyon a mile up-stream (south) from Fisher's Tank and about 5 miles southeast of Flagstaff. By their first count this tree was 640 years of age when cut and subsequent examination confirmed that figure. By courtesy of Mr. G. A. Pearson, director of the Southwestern Forest Experiment Station, a large half section was cut for me and

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A. Site of 500-year pines, Flagstaff, Fl. 35, in foreground; looking south

B. Stump of 640-year pine, Fisher's Tank, Flagstaff

sent to Tucson, and later (July 13, 1926) he showed me the stump, of which I include here a photograph (Plate 6, *B*). The canyon is about 200 feet deep in the horizontal limestone strata and extends north and south. Water flows occasionally. The stump is on the east side of the canyon, 25 feet above the bottom and 50 yards from the usually dry wash. The slope of ground about it is about 30°. The date of starting was undoubtedly close to 1275 A. D. The earliest measured ring is 1284, but a serious injury occurred, probably in 1294, greatly reducing the growth for some 8 years. Much decay has occurred at this point, and though the dating is probably correct, the normal values of the ring-width are profoundly reduced. Since the first hundred years in this record were new, three radii were measured and the average taken. The growth is somewhat complacent, but much information is given by it for that century. It is probable that important checks on it will be obtained from early historic beams in the Hopi pueblos. This discovery renewed interest in the search for very old trees, and it is possible that some living trees of similar age have already been found.

Other 500-year pines—A 500-year pine was found in the group of 8 from the Charleston Mountains, near Las Vegas, Nevada. It showed with the other trees there a record rather intermediate between the Arizona and California values. Also a fine V-cut from a pine stump in the Crater National Forest of southern Oregon near Kirkford has been sent me by the kindness of Lumberman John D. Holst, of that locality, acting for Mr. Fred Ames, assistant district forester at the Portland, Oregon, office. In this connection, also, one might mention the extraordinarily old juniper near Logan, Utah, of which a description has come from Supervisor C. B. Arentson, located there.

PREHISTORIC MATERIAL

The search for old pine records has taken a new turn in the use of early historic and prehistoric pine logs in the Hopi villages and the ancient ruins of the Southwest. This really began in 1916, when Mr. Earl H. Morris, for the American Museum in New York, sent me several early historic logs from Gobernador Canyon, near Aztec, New Mexico. This led to a series of specimens from the ancient ruin at Aztec.

Aztec sections—A trip to Aztec was made in August 1919. An examination of the logs in this ruin led to the construction of the tubular borer, which produces cores 1 inch in diameter, giving the series of rings from the outside to the center of the log without impairing its strength and without disturbing the original house construction. Following this visit, Mr. Morris spared no effort in getting me specimens from some 50 logs used in the construction of that wonderful ruin. Nearly all of these cross-identify perfectly in the Aztec-Pueblo

Bonito chronology. It seemed necessary to get some modern trees from that vicinity, so Mr. Morris took me 40 miles north to Basin Mountain, in southwest Colorado, where some 10 different trees were sampled. To these were later added 9 tree sections from a point about 20 miles east of Aztec. These together make a very satisfactory group known in my lists as the "Modern H's," H being the group letter applied to the old Aztec material.

Chaco Canyon beams—The Aztec sections gave a fine ring record more than 200 years in length, but of unknown date. As soon as its real date becomes known, that much length can be added to the climatic record in the southwestern pines. An early shipment of Aztec sections included several from Pueblo Bonito in Chaco Canyon, some 50 miles to the south. These specimens came from the American Museum in New York City, where they had been deposited by the Hyde Expedition 25 years before. Very soon these were found to cross-identify with the Aztec sections, and they began to improve and extend that prehistoric record. Then Mr. Neil M. Judd, director of the National Geographic Society Expedition at Pueblo Bonito, became interested in the possibility of developing the chronology of Pueblo Bonito by the ring records and he has collected and sent me nearly 160 excellent specimens, mostly from that one ruin. Nearly a hundred of these I have been able to place exactly in the Aztec and Pueblo Bonito chronology. This chronology is referred to as R. D. or relative date, since its true location in our numbering of years, "Anno Domini," is unknown. This Pueblo Bonito material has increased the prehistoric ring record so that it extends accurately from R. D. 230 to R. D. 543, a range of 313 years. A single beam extends it with uncertainties about 40 years later. So if this material could be dated, some 350 years of record would be added at one stroke.

In connection with this collection two trips have been made to Chaco Canyon, one in early September 1922, to get a better knowledge of the beams there and of the problems connected with their dating, and the other in September 1926, to study the living pines in that region. On each occasion many specimens were collected, and on the second trip much was seen of special interest in connection with climatic indicators in trees, which will be mentioned in a later chapter.

National Geographic Society beam expedition—It is evident that two different interests join in the attempt to date the beams in the ancient ruins of the Southwest, namely, the extension of climatic and solar records in trees, and the archæological and human interest in the age of those wonderful ruins. For the second reason, the National Geographic Society has encouraged and supported the further collection of early historic and prehistoric material and otherwise assisted in the dating of these prehistoric beams. In general, two distinct

dating methods are in view. The first is the "bridge" method, by which we start with old living trees and cross-date the early parts of these with late parts of earlier trees, and so on till a real ring record is built back to the age when the ruins were under construction. The other method is the "sequoia comparison" method by cross-dating with the sequoias, whose great age without doubt covers the period of building of these ruins. The best result would be one derived from a complete agreement of these two methods. Perhaps the stronger of the two methods is the first or bridge method, but it promises to require large collections from many different ruins, beginning with the early historic and going back to the period desired. Consequently, in June 1923 an expedition set out for the purpose of making such collections under the charge of Dr. J. A. Jeançon of Denver, assisted by Mr. O. M. Ricketson, of the Carnegie Institution. I went with them for the first 10 days in their visits to the Hopi Indian villages, where some 22 specimens were collected. They then continued the trip, covering generally the southwestern area, including such places as Canyon de Chelly, Chaco Canyon, Mesa Verde, and the Rio Grande Valley. To the present time their collections have not been finally and thoroughly examined (such work will be done in connection with the study of past climates), but it is practically certain that extensive gaps remain in the long interval from the Aztec and Pueblo Bonito chronology to A. D. 1300 or 1400, when the living trees began their record. Nevertheless, this bridge method is probably only delayed, for the collection from Pueblo Bonito reveals the possibility that in some Hopi Pueblo or late prehistoric ruin will be found beams cut in ages different enough to cover the long interval desired.*

CALIFORNIA AND ARIZONA CROSS-DATING

In the presence of the gaps above referred to, the sequoia comparison method becomes of increased importance and has played an important part in directing our effort in the last few years. The visit to the Calaveras Grove in 1924 and to the Springville Grove in 1925 were primarily to aid in this problem. The problem itself was stated above in describing the purpose of the fourth sequoia trip, page 52.

CHARLESTON MOUNTAIN TRIP

In connection with the dating problem between Arizona and California, the Charleston Mountains, at the southern extremity of Nevada and about midway between the Flagstaff area and the best sequoia region, were visited and collections made. Senator E. W. Griffith, of Las Vegas, Nevada, kindly took me out on July 9, 1924, by automobile

*At the time of reviewing this chapter a group of 25 beams from "Wupatki" near Flagstaff has shown that this ruin was built some 30 years later than Aztec. It seems very probable that in time the "bridge" method will be successful.

some 30 miles west to the summer resort at about 7,500 feet elevation in these mountains. The resort is located in a large, deep canyon on the east side of the mountain and well up in the pines. A delightful brook runs much of the time. The ring record from the trees collected here is actually intermediate between Arizona and California, agreeing in some parts conspicuously with the Arizona trees and in other parts with California. The full discussion of these characteristics, in order to see whether they help to solve the cross-dating problem, is planned in connection with the study of past climates.

VII. TREE RECORDS: GEOGRAPHICAL DISTRIBUTION

The understanding of any special distribution of ring characters over great areas is increased by personal acquaintance with the region. So, in addition to much travel in the Southwest, both within and without the State of Arizona, the writer has made two special trips in the study of geographical distribution of tree-growth.

WESTERN CIRCUIT, 1925

This trip was made easterly from Tucson to the Rio Grande Valley, thence up-stream to Albuquerque and east again to Santa Fe, where the SF group had been collected in 1922; thence through the pine-covered mountains to Las Vegas. Halfway between these cities we passed Pecos, where the "L" group of four trees had been obtained, by aid of the Forest Ranger. However, only one of these proved suitable for dating, and so this is not retained as a group. The next day carried us over the wide elevated plains of northeastern New Mexico to Raton, whose mountain pass through the Rockies is high enough to be pine-covered. Three of the trees near the road were bored, but only one could be dated reliably, and as we already had a group from Cloudcroft, New Mexico (CC group), this single tree is omitted. Later we went along the eastern base of the mountains to Fort Collins, Colorado, and Laramie, Wyoming. In the low hills between these two places, the group LW (Laramie, Wyoming) was collected near the road.

The eastern face of the Rocky Mountains, extending north and south for many hundreds of miles, is a striking feature of western contours, and the groups in New Mexico, Colorado, and Wyoming along this line and partly also the small Yellowstone group from Specimen Ridge in the northeast corner of the park (collected in 1920) give certain interesting characters which will be referred to later.

The next stop for collecting was 60 miles northwest of Baker, Oregon. At a point where pine trees border the road as it passes over the Blue Mountains, the BO (Baker, Oregon) group of 8 was collected. On the eastern slopes of the hills near the road at The Dalles are more yellow pines, of which a small collection was made, known here as the DL (Dalles) group. In the low coast hills 25 miles northwest of Portland, a large group of Douglas firs was collected in 1912, as described in Volume I. It now appears that this group, called OC (Oregon Coast), does not cross-identify with the other western groups, probably because its location close to the coast gives a very different climatic environment.

The primeval forests of the State of Washington were extensively cut along the settlement-line marked by the highway between Portland and Seattle. Much of the land was burnt over and the huge

burnt stump is a common sight. Stumps were examined in different places and ring samples were collected at Victoria, British Columbia, at Blyn, Washington, and at Toledo, on the Oregon coast, but the growth was so exceedingly complacent that no special effort was made to form a group. However, there is no real doubt that group characters will show, if the right tree and location are found.

WESTERN CONTOURS AND RAINFALL

The important mountain ranges of the western States extend in north-and-south rows, whose western slopes precipitate moisture from the westerly winds. The long valley running north from the Gulf of California, with the smaller parallel San Joaquin Valley in central California, is the driest area, because the westerly winds are drying winds as they descend into them.

Mechanism of Arizona summer rains—The maximum rainfall on the coast is in winter, but the maximum in the northern parts of the dry valleys just mentioned is in late spring, when their warming causes the air to rise and move to the east and "pull" in the westerlies. In midsummer it is so hot that the moisture is reabsorbed even before it falls and the amount that reaches the ground is small. The same summer "pull" draws moisture-laden air from above the Gulf of California far to the south (whose water temperature at Port Libertad in September 1923 was 87° F.), and perhaps from other warm bodies of water. This air, as it is drawn up over the mountains and plateaus in its northward-moving path, gives up its moisture in the common torrential summer rains of that region, strongest near the Gulf and fading out in Utah.

Prediction possibility—If this statement of the possible mechanism of our summer rains is correct, it would seem possible to predict their amount, some months at least beforehand, by some formula involving chiefly the mean temperature of the water in the Gulf of California and of the desert areas of the western valleys.

The Rocky Mountains—The Rockies are high enough to catch the westerlies and intercept a remnant of their moisture, and thus they partake year by year to some degree in the winter variations which come to the Pacific Coast. But in the warmer months the mechanism just referred to as acting north from the Gulf of California produces a similar effect north from the Gulf of Mexico, and the eastern Rockies show a great summer maximum.

THE THREE ZONES

Thus, in reference to climatic types, there are three zones lying in north-and-south strips delineated by the mountain ranges. On the west is the Pacific or Coast zone, where the precipitation is only in winter, from the westerly winds coming in off the ocean. The arid interior region forms the Arizona zone, whose higher points where the pines

grow intercept the westerlies and partake strongly in the variations of the coast. This zone has a secondary rainy season in midsummer, torrential in character and producing for the most part only slight effect on the tree-growth. To the east is the Rocky Mountain zone, which catches a remnant of the coastal variations and gets its chief moisture supply in summer.

Latitude effect—In each of these zones there is a strong latitude effect. On the coast the westerlies are very powerful in the higher latitudes, weakening south of San Francisco and becoming gentle at San Diego. They disappear entirely in the tropics. In the valleys of the central zone the spring rainfall maximum of the north changes to the well-defined winter and summer rainy seasons of Arizona. The eastern or Rocky Mountain zone has less latitude change than the others. The total rainfall increases as we go south by the increasing amount of summer rains. In Texas, and still more in Mexico, it begins to show a temporary diminished rainfall in July and August at the very peak of the maximum. Perhaps this is actually the tropical winter minimum of the southern hemisphere reaching over thus far into northern latitudes.

THE PUEBLO AREA

The Pueblo area trip was made in behalf of the National Geographic Society in connection with studies of the Pueblo Bonito chronology. It seemed advisable to visit and test the pine and spruce regions from which the prehistoric Indians drew their timbers and find out whether such regions agree with the Flagstaff areas in their tree-growth.

The Hopi villages—These villages, still occupied, lie along the southern edge of a raised and sloping plateau called the "Black Mesa," whose surface is dissected by canyons and whose highest point, some 75 miles north of the villages, is near Kayenta.

Kayenta—The 24-hour trip from Flagstaff to Kayenta was made on September 4 and 5, 1926. The settlement is in a valley just east of Mount Lolomai, the highest point of Black Mesa. Mr. John Wetherill, for many years well known in this region, took us to the mountain top, 4 miles in a car, 4 or 5 more on horseback, and then a climb of 700 feet on foot. Samples collected in several different places all show the Flagstaff ring record, as do the rings in the beams of the Wetherill house.

On September 7 we started to Chin-lee, 72 miles southeast, passing Chilchinbeto at 16 miles and confirming the agreement between Black Mesa and Flagstaff by some specimens there.* At Chin-lee we cut radials from logs in the store of Mr. L. H. McSparron, who very

*Later, on the return trip, we stopped at Oraibi, the westernmost of the Hopi villages, and cut radials from logs of spruce from Piñon, 30 miles northeast, with the same result.

kindly gave the necessary permission. These logs came from the Lukaichukai Mountains east of the Chin-lee Valley, south of the Chuskas and north of Fort Defiance and Gallup. A day on horseback was spent in the wonderful canyons there, De Chelly and Del Muerto. Then we drove southeasterly up onto the Lukaichukai Mountains and obtained borings in several places, ending at the sawmill 13 miles north of Fort Defiance. These borings and the radials from Chin-lee agree with the Flagstaff series.

We motored southeast to Gallup and then 100 miles northeast to Chaco Canyon, and there a most interesting search was made for living pines, a number being found at distances of 2 to 20 miles east of Pueblo Bonito. These pines, which appear to be a remnant of a great forest on those mesas in past ages, also show the Flagstaff series of rings. From Chaco our return trip carried us to Gallup, Holbrook, and the Petrified Forest, Keam's Canyon, Walpi, Oraibi, Leupp, and Flagstaff, 16 days from leaving it.

Rio Grande Valley—During a trip to the Rio Grande Valley in April 1927, specimens of tree-growth from the Zuni Forest, south of Grant's, New Mexico, and from the Jemez Mountains, west of Santa Fe, were obtained. Each locality shows a perfectly clear Flagstaff record.

Navajo Mountain—By courtesy of Mr. H. Richardson, a trip was made in May 1927 to Navajo Mountain, Rainbow Bridge, and Rainbow Lodge. Specimens of Douglas fir from the south slopes of the mountain show a perfect Flagstaff record. These recent collections therefore leave no further doubt that the whole Pueblo area west of the Rio Grande is homogeneous in its tree-growth and forms part of the large Flagstaff area.

SOUTHWESTERN CONTOURS

The large southwestern arid area is bounded on the west by the range of Southern California mountains, including San Antonio, 10,080 feet, San Bernardino, 11,600 feet, and San Jacinto, 11,000 feet, which, therefore, form a great rampart impeding the westerly winds. East of this range is the Imperial Valley, with the Salton Sea some 200 feet below sea-level. The Charleston Mountains form an isolated island at the southern point of Nevada. East of the Colorado River the land rises to the plateau of northern Arizona, while in the southern part of Arizona the land rises to the east very gradually, with many "island" mountains high enough to have pine trees upon them. The Mogollon Mesa, often called the Rim, is the bold and lofty southern edge of the Colorado plateau. It cuts across the central part of the State, pointing generally a little south of east. South of it are the island mountains; north of it the land descends gently to the Little Colorado River and then

rises gently to the States on the north. On this slope the great Black Mesa has large cedar forests, with pines in the canyons and along the northern edges. Then to the east is the Chin-lee Valley, and east of that, on the border between Arizona and New Mexico, is the range called Chuskas on many maps, with a southern part called the Lukaichukais. These carry extensive pine forests. The next pine-covered range is a hundred miles east and forms the western boundary of the Rio Grande Valley. This range has Mount Taylor at its southern end and the Jemez Mountains west of Santa Fe. Chaco Canyon is in the large area between the Chuskas and the Jemez Mountains. It is surrounded by mesas which probably once held pine forests, but the mountains just named are higher and its rainfall is small. East of the Rio Grande Valley the big masses of the Rocky Mountains begin.

WESTERN PINE GROUPS

Statistics—The whole number of tree records minutely examined up to date is about 1,100, and the total number of rings is close to 210,000. Of these, about 175,000 have been dated and measured. The extensive failures to date the coast redwoods are largely responsible for this difference between rings examined and rings measured, and many of the groups have had a small proportion of the trees which could not be dated. The number of trees included in the 42 groups whose cycles are studied below is 305 and the number of rings dated and measured is 52,400. These trees are practically all western yellow pines, with a few Douglas firs here and there.

Zone statistics—The 42 groups are divided into three zones: (1) the interior or Arizona zone, where this study began and has had the greatest extension; there are 14 groups in this zone, with 104 trees and 21,210 measures; (2) the eastern or Rocky Mountain zone has 15 groups of 82 trees and 14,135 measures; and (3) the western or coast zone has 119 trees in 13 groups, with 17,055 measures.

Miscellaneous groups—A number of other groups not included in the subsequent discussion of cycles follow the western pine groups. They consist of groups of different kinds of trees, groups of good trees which did not have enough material, such as the Raton and Pecos groups of yellow pines with only one record each, of trees which could not be dated, such as the coast redwood, and of groups from distant localities.

Group treatment—In the 42 western cycle groups only the individuals are used which can be dated and also only those parts of each individual which can be dated with certainty. In nearly every group the curve of each individual tree has been standardized as described in a previous chapter. Thus the different trees in a group have equal weight and the age effect in the trees is largely removed.

Analysis—Three analyses were made, namely: (1) the full length of the group curve, using maxima; (2) the part of the group curve subsequent to 1750 A. D., using maxima; (3) the part of the group curve subsequent to 1750 A. D., using minima, that is, plotting an inverted curve and then cutting out and analyzing the higher (negative) ordinates as usual.

Precautions—Knowing the possibility of prejudice and systematic error in analyzing this large number of curves, several precautions were observed: (1) Settings of the White cyclograph were made without knowing what the reading was going to be; (2) full analysis of each curve was made without knowing which curve it was; (3) each of the three analyses was carried through the complete list of curves in one continuous sitting of four or five hours, so that possible errors of adjustment or of judgment would apply equally to all groups; (4) the instrument was calibrated from time to time with standard curves, and its errors were of the order of one-tenth of a unit of period, which is less than the error of an average setting, which is one to three tenths of a unit, depending on conditions. Four critical parts of the reduction process were invariably done by the writer, namely, dating the rings, drawing the standardizing line, marking the cutting line for the cycle plot, and making the cycle analysis. Other parts were done mostly by assistants, such as mounting, measuring (checked afterwards by the writer in most cases), tabulation, plotting, smoothing, and tracing and cutting the cycle plot.

Analysis report—A cycle is reported below only when it occurs in two of the three analyses, and its relative excellence is shown by a number in parentheses following the cycle-length. This number may be considered a "weight" and so an approximate amplitude. Unit weight, meaning medium or average conspicuousness of the cycle, is omitted. Weight 2 means a fine cycle and weight 3 a remarkable cycle as viewed in the cyclograph. Cycles occasionally show a lesser secondary maximum and very rarely two secondary maxima. In such cases the fraction $\frac{1}{2}$ or $\frac{1}{3}$ respectively, in the parentheses with the weight, gives indication of this doubling or tripling.

Abbreviations—For convenience, the names of the groups are sometimes reduced to an abbreviated form which consists of some initial letters as suggestive as possible. These letters are given after the group title.

ARIZONA REGION

FIRST FLAGSTAFF GROUP (FL)

This group was collected in 1906, 1 or 2 miles west of Woody Mountain and some 10 miles southwest of Flagstaff. Nineteen trees numbered 7 to 25, were used; Nos. 1 to 6 were not preserved and there-

fore were not corrected by cross-identification, which was applied to the others in 1912. The 19 original sections have been retained and two sets of radials have been cut from them; one is the set measured in 1906 and cut in 1912 and the other was cut about 1925, so that accidental loss of the fragmentary pieces of the original sections would do no harm. The curve values as extended to 1910 are given in the appendix of Volume I, to which volume reference is also made for the curve itself (p. 25) and further details. Measures were by ruler. There were so many in this group that for the present purpose it did not seem necessary to standardize each tree-curve, as has been done in nearly all of the western-pine groups. The smoothed curve shown in figure 4 was made by a graphic Hann. The cycles are 6.9 (3), 13.6 (3), 20.6 (2), and 28.3 ($\frac{1}{2}$).* It still remains uncertain whether the cycle 20.6 years is a real value or whether it is a combination of two, of which one is under 20 years and the other about 21 years.

FLAGSTAFF 500-YEAR GROUP (FLU)

This group was collected September 10, 1919. Mr. J. F. Freeman measured the specimens by the cathetometer method. Long records were sought at that time and the two 500-year trees, Nos. 12 and 13 in the previous Flagstaff series, were completely remeasured and added to the five similar trees in this group, Nos. 33,† 34, 35, 37, and 40, and a table of seven (unstandardized) trees produced. It is a plot of their averages, 1750 to 1917, of which a graphic Hann is shown herewith in figure 4. The use of the same two trees in each of these Flagstaff groups probably has no real effect on the similarity between the two groups, which is very marked, for all these trees give very nearly the same record. The cycles found in this group are 14.0 (2), 20.6 (3), 26.7 ($\frac{1}{2}$), 29.1 ($\frac{1}{2}$), and 40 ($\frac{1}{2}$). The 20.6 varies from 20.2 to 21.0. The two near 28 are perhaps variants of one cycle.

FORT VALLEY GROUP (FV)

This group is made up of complete sections cut in Fort Valley, 12 miles northwest of Flagstaff, by Mr. G. A. Pearson, for the purpose of studying group effects, or the effect on tree-rings of near neighbors. But practically no effect was found unless the neighbor was within 5 or 10 feet. The trees grew one-quarter mile northeast of the experiment station, elevation 7,300 feet. Mr. L. R. Patterson measured these rings by the auto-plot method. Each tree was standardized. The final table and plot were made by Mr. W. G. Austin and the cycle plots by Mr. F. M. Douglass. The curve 1686 to 1920, shown from 1750 in figure 4, resembles FL and FLU and is equally typical of the

*It will be noted that this fraction means doubling and not weight.

†Nos. 26 to 32 were cut east of Lake Mary in 1911 and are often called the LM group. They are given in the curve on page 27 of Volume I, and as they were only small pieces cut from the edge of the stumps, they are not used in this study of western cycles.

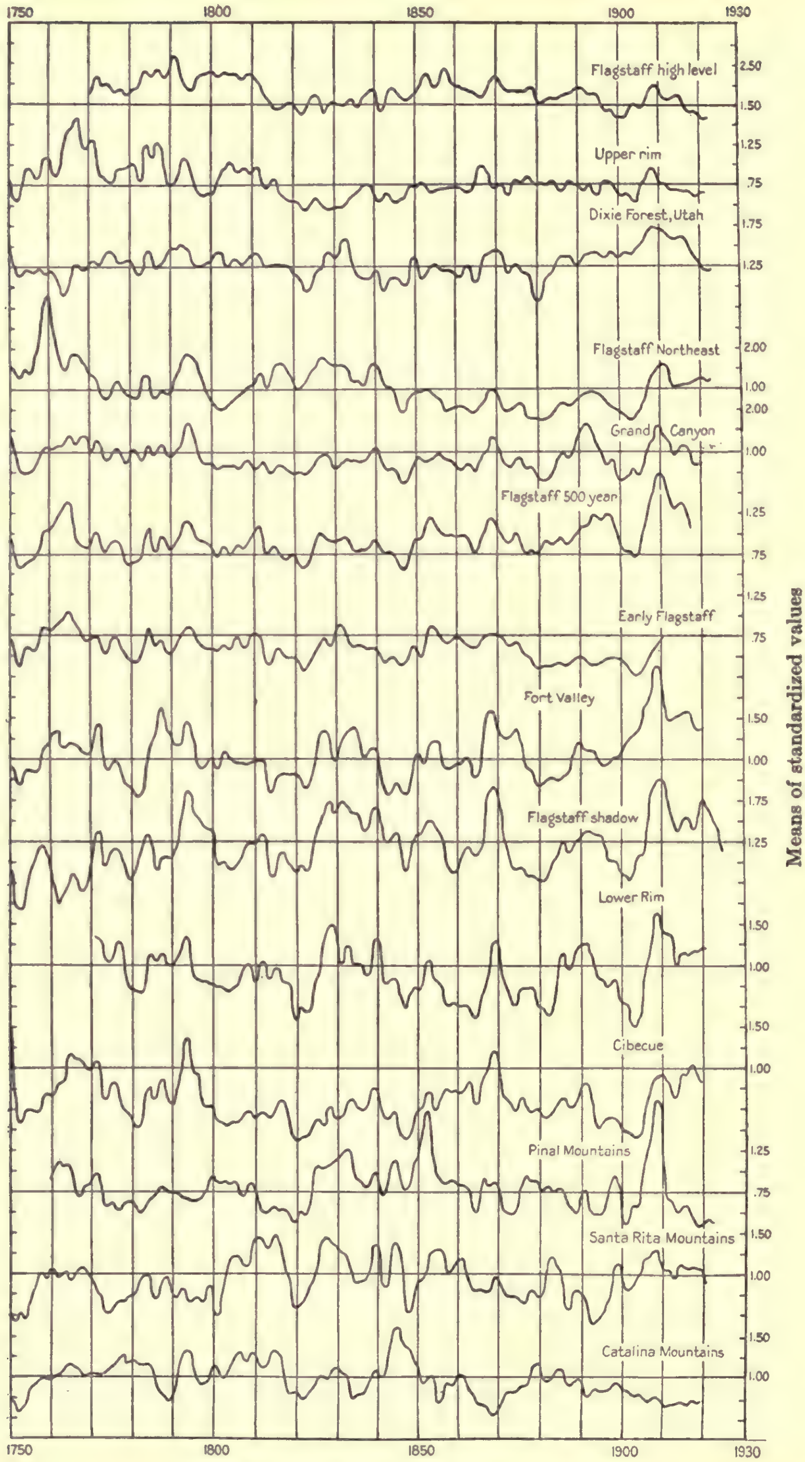

Fig. 4—Arizona zone, smoothed group curves

central Arizona area. It shows cycles as follows: 13.1, 14.5, 18.5, 20.5 (3), and 35 (3, ½). The 13.1 and 14.5 are very possibly variants of one about 14 years. The 20.5 again varies from 20.0 to 21.0.

HIGH LEVEL GROUP (FLH)

The idea of testing the effect of altitude on the ring-growth was held from an early date. The first actual collection for it was done on June 19, 1920, when Dr. E. J. Brown and the writer went on foot up the canyon above Shultz Pass, where the Weatherford Boulevard has recently been constructed. But the specimens were crudely cut and it was felt that it would be preferable to test tree-growth on the west or southwest slope of the mountain. Accordingly, on July 11, 1920, a trip was made up the southwestern ridge of the mountain from the southern end of Hart Prairie to the cabin used by the experiment station at an elevation of 10,500 feet. Director Pearson and Mr. Haasis of the staff were of the greatest assistance. A very interesting group, numbered Fl 69 to 80, was obtained, including Douglas fir, cork-bark fir, limber pine, fox-tail pine, and Engelmann spruce. But this seemed to combine too many different species over too great a range of altitude; accordingly, the group of yellow pine increment-cores here used was collected with the aid of Mr. Pearson on July 12, 1924, at elevations averaging a little under 9,000 feet, that is, really in two subgroups, one at the south end of Hart Prairie and the other at a little over 9,000 feet altitude.

These 10 cores were measured by Mr. D. A. Hawkins, using the long-plot (longitudinal plot) method, and were then tabulated and averaged and the curve, 1770 to 1923, plotted without standardizing. A graphic Hann, shown in figure 4, was made by Mr. F. M. Douglass. In general appearance this smoothed curve has all its variations greatly diminished and is otherwise somewhat discordant compared to the usual Flagstaff tree-records. It introduces a 17-year cycle, which is not common in this region; but its cycles belong to the Arizona class and are as follows: 6.9 (2), 9.1 (oc. ½), 13.7 (2, ½), 17.3 (3), 20.5 (2, oc. ⅓), 27 (oc. ¼), and 35 (2, oc. ½).

FLAGSTAFF SHADOW GROUP (SH)

The old-time winter road to all points north of Flagstaff passed east of the San Francisco Mountains because it was drier, warmer, and had less snow than the west side. The forest regions east and northeast of the peaks are shaded by the mountains from the wet westerly winds, and the special effect observed in this group and others is called the shadow effect. This group of five Swedish increment-cores was collected on July 13, 1924, in a specially selected area nearly on a line between Sunset Crater and the peaks, and about half a mile west of the main highway. At this place the elevation is very

little above that of Flagstaff and is about the same as that of the Fort Valley group, with which the curve, therefore, can be compared for the shadow effect. Mr. Hawkins measured these specimens by the long-plot method and, without standardizing, plotted a curve from the averages. This curve, 1717 to 1923, was Hanned mathematically and the cycle plot was made by him also. This smoothed curve from 1750 on is shown in figure 4. The great variation between maxima and minima is at once apparent and is characteristic of lower and drier altitudes. The shadow effect does not appear to differ much from simple reduction in rainfall, equaling in this case the effect of about 1,500 feet change of altitude. The spacing of the maxima is strongly of the Flagstaff or Arizona type. The observed cycles are 14.1 (3), 19.4 (2), 27.3 (2, ½) and 40 (2, oc. ½).

FLAGSTAFF NORTHEAST GROUP (NE)

This group was collected on June 14, 1923, in connection with prehistoric dating problems, to determine with certainty whether the part of the Flagstaff forest area nearest the prehistoric ruins carries the same ring records as the very old trees just south of town. Dr. E. S. Miller, of Flagstaff, was kind enough to take me out 19 miles on the Tuba road and there, at the edge of the forest, I took four increment-borings. Mr. Hawkins measured these in 1923 by the auto-plot method. These were thoroughly rechecked by the writer (as in all cases). These individuals were so nearly alike in average growth that they needed no further standardizing. The curve, 1678 to 1922, identifies exactly with the Flagstaff record. It was smoothed by graphic Hann by Mr. Austin and the part from 1750 on is shown in figure 4. The cycle plot analyzes as follows: 8.5, 11.6 (2), 14.3 (2, oc. ½), 19.4 (2), 27.7 and 36 (2); these classify as Arizona type, though the 11.6 is not so common as on the coast.

GRAND CANYON GROUP (GC)

The edge of the Grand Canyon is 65 miles north and a little west of Flagstaff. Leaving the San Francisco Peaks and traveling north, one descends gradually for a time away from the pines, down through the cedars, across a barren area, then up gradually through the cedars and into the pines which border the canyon. Much of the forest area near the canyon is perfectly flat. The Grand Canyon group was taken in early July 1920, at points scattered several miles along the south rim from a little west of Grand View to the Buggeln property, which used to be Tolfree's Hotel, at the top of the old historic Hance Trail, a distance of 5 or 6 miles. The soil here is a thin layer of earth over limestone. There appears to be very little surface drainage and it is probable that the water soaks down through the limestone formation and emerges in springs in the canyon. In the early days, Tolfree's got its drinking-water from artificial "tanks" or pools of standing water

formed from the melting winter snow. Mr. Patterson measured 7 of this group of eight v-cuts by the auto-plot method in 1922. Each tree record was later standardized, tabulated, and plotted by Mr. Austin in a curve from 1716 to 1919. This curve is of perfect Flagstaff type. The graphic Hann shown in figure 4 was made by Mr. F. M. Douglass in 1926. The cycles belong to the Arizona classification, as follows: 11.7, 14.5, 18.4, 20.8 (2), 23, and 36 (oc. ½).

DIXIE FOREST (UTAH) GROUP (DF)

This is a group of Swedish increment-cores collected and sent me by Mr. William M. Mace, supervisor of the Dixie National Forest, from the Pine Valley Mountains, in the southwestern corner of Utah. As in the case of the Charleston Peak of southern Nevada, it seemed desirable to find some groups intermediate in position between the Flagstaff area and the region of the big trees of California. Mr. Mace writes that these specimens came from the westerly side of the mountains at an elevation of 8,500 feet. This would seem to correspond in topography to group FLH, but their record, though very complacent like FLH, resembles FL more than FLH does. The cores were received October 1, 1923. Mr. Austin measured them by the long-plot method in 1926. Each tree was standardized and the table and averages and plot were also made by Mr. Austin. The curve extends from 1616 to 1922 and shows good resemblance to the Flagstaff curve. It was smoothed by graphic Hann and is thus shown from 1750 in figure 4. Its cycles are of the Arizona type, as follows: 19.6 (3), 27.1, and 40 (2, oc. ½).

UPPER RIM GROUP (RH)

Next to the Grand Canyon, Arizona's most remarkable scenic feature, on a large scale, is the Rim. This is the abrupt southern edge of the great Colorado Plateau. It is an ancient fault-line; the rocks to the north average 7,000 feet above sea-level and 1,000 to 2,000 feet higher than those to the south, with other steep slopes below, so that from the Rim one looks over enormous stretches of Southern Arizona with its island mountains showing faintly in the blue haze of distance. The edge of the Rim stretches across half of the State in a generally uniform direction, but is wavy or zigzag in detail. So, when seen from below, for example, from near Pine or the Natural Bridge, its sinuous length extending easterly as far as the eye can see, could be classed as one of the wonders of the world.

An extraordinarily large and pure pine forest covers this Rim and the adjoining slopes, connecting on the north with the Flagstaff area and extending on the east past the White Mountains and into New Mexico.*

*Years ago, by kindness of Mr. F. S. Breen, then supervisor of the recently created national forest, it was my privilege to traverse this Rim from Camp Verde to Nutrioso, close to the New Mexican border, in a buckboard. I have no doubt that 600-mile trip from Flagstaff, lasting 26 days, helped to originate this investigation of the history recorded in tree-rings.

Thus the bold, pine-covered headlands of rock overlooking southern Arizona differ in topography from the Flagstaff region, and it seemed worth while to get a group of borings in such a locality. This was easily done in a motor trip from Tucson to Flagstaff, on which I was assisted by Mr. T. J. Randolph. The borings were made on August 26, 1922, two of them at 6,000 feet elevation, near the fork in the highway between Pine and Strawberry, where the road to Flagstaff starts up the big grade. These were numbered 91 and 92 in the Flagstaff series and form the group RL. Two other borings were made at the top of the Rim, where the elevation is 7,000 feet. These were numbered 93 and 94 and constitute the present group RH. It was intended to include all of these four in one group, but the two locations proved so different in their effect on ring-type that it was thought best to separate the pairs. The individuals of each pair agree finely. Mr. Hawkins measured these four cores by auto-plot method. They were then completely rechecked by the writer and individually standardized. The tables and curves were done by Mr. Austin. The curve of the Upper Rim group, 1697 to 1921, smoothed by graphic Hann, and shown in part in figure 4, is very complacent, and has only moderate similarity to the typical Flagstaff curve. Its cycles, however, keep it in the Arizona zone, for they are as follows: 14.7, 19.9 (3), and 37 (2).

LOWER RIM GROUP (RL)

This group, as described in connection with the preceding, consists of two increment-cores collected August 26, 1922, near the fork in the road at the foot of the long Strawberry grade. The elevation is 6,000 feet. Its location is a south exposure with the great thousand-foot wall of the Rim immediately to the north and a low, flat-topped mesa "island" close to the south, standing up a few hundred feet. The curve, 1770 to 1921, smoothed by a graphic Hann, is shown in figure 4. Its striking variations resemble a shadow effect like that in the SH group, which it minutely resembles. In fact, the remarkable likeness between this curve and those of FLU, FV, SH, NE, GC, and J groups puts this collection of groups in a distinctive homogeneous class whose locus extends at least from the Grand Canyon to the Rim, a distance of about 150 miles. The RL cycles are 10.1, 12, 20.1 (3), 23.7, 27.6, and 38 (2, oc. $\frac{1}{2}$). The absence of 14 years makes it resemble the cycle of the Rocky Mountain zone, but as 14.4 did appear in good form in one of the three analyses, its place in the Arizona zone is justified.

CIBECUE GROUP (J)

The Cibecue group of five increment-borings was collected on July 23 and 24, 1920. The area included in this group extends from the store on Grasshopper Creek (15 miles west of Cibecue Creek store) to the small creek about a mile east. This is some 20 miles south of

the Rim and about halfway between Pine and Fort Apache. The elevation is under 6,000 feet. The region is reached by motor from the White River Indian School near Fort Apache. The cores were measured by Mr. Patterson, using the auto-plot method, and fully rechecked. The curve, 1652 to 1919, was plotted directly from the averages and cross-identifies closely with the Flagstaff record. The graphic Hann from 1750 on is shown in figure 4. It resembles RL strongly. The cycles are 8.2, 9.6, 12.1, 18.5, 23.8 (3), and 30.5. There was no sign of a 14-year cycle, and therein it resembles the Rocky Mountain curves.

PINAL MOUNTAIN GROUP (PNL)

Surrounded by the lower levels of southern Arizona, the Pinal Mountains form an island 90 miles from the Rim groups described above. To reach them from that part of the Rim, one motors down Tonto Creek and after leaving Four Peaks on the right, passes Roosevelt Lake and Dam. Twenty-five miles beyond are the cities of Globe and Miami, south and west of which are the Pinal Mountains. A road goes to Tucson over each flank. To the east is the Winkelman road ascending almost to the pine level; to the west is the Globe-Superior Highway, a splendid bit of road engineering over a rocky and picturesque table-land. Four borings were made September 5, 1924, above the camp-grounds, southwest of the main peak. These cores were measured by Mr. Swan Erickson, using the long-plot method. Each tree of the three usable ones was standardized and the resulting curve (see fig. 4) shows distinct resemblance to the Flagstaff curve—more in fact than do the curves of the other island mountains. The cycles are 7.6 (2), 10.1, 14 (oc. $\frac{1}{2}$), 23, and 27. This grouping of cycles is classed as general, since it is rather deficient in the special characteristics of each zone.

CATALINA MOUNTAIN GROUP (SC)

The Catalinas are about 60 miles a little west of south from the Pinals. They are a large, rambling mountain mass without distinctive top and form an emphatic northern boundary to the Tucson Valley. The main summit, Mount Lemmon, elevation 9,150 feet, has an inconspicuous rounded top with a fire lookout. Close on its southeast edge is the resort, Summerhaven, with an easterly ridge extending 4 or 5 miles to Bigelow Peak and beyond. Central on this ridge is the beautiful little valley known as Bear Wallow, with the ranger station and Soldiers' Camp. The SC group consists of eight increment-cores and one 350-year V-cut, all usable except one core. Their location extends from Summerhaven to Mount Bigelow. Some are on the very crest of the ridge and some are a hundred feet or so lower down on the south side. The average elevation is about 7,500 feet. The contours

are given in some detail, because this group, while internally very satisfactory, is as a whole the most discordant in the entire Arizona area, both in cross-identification of rings and in comparison between smoothed curves. The SC specimens were measured part by auto-plot and part by long-plot method. Individual trees were standardized. The final curve, 1567 to 1919, shows a very limited resemblance to curves in the Flagstaff area. After being smoothed by graphic Hann, it shows many reversals of Flagstaff growth, for example, the years near 1630, 1670, 1730, 1847, and 1880 have big growth instead of small. The part since 1750 is given in figure 4. The cycles are 7.5, 9.2 (oc. ½), 11.3, 17.4 (2), 22.9, and 34.7 (3, oc. ½). The presence of 11.3 and 17.4 gives it a resemblance to the Rocky Mountain zone which incidentally has a number of reversals compared to Arizona.

SANTA RITA GROUP (SR)

The Santa Ritas, 9,400 feet in elevation, are 50 miles due south of the Catalinas and form a massive mountain boundary on the east side of the Santa Cruz Valley south of Tucson. The mountain slopes are steep and the summit itself forms an upstanding monument of rock 500 feet high, very striking in appearance. The pines cover the upper parts of the mountain, but favor the north-facing canyons where the snow lingers. Some Mexican species of pine are found here, but they closely resemble the western yellow pine. A group of 10 borings was collected in the upper parts of White House Canyon, the summer-resort region, on May 2, 1921, but these could not be dated, as the doubling of rings by the pronounced summer rains made the annual character very uncertain, a summer condition much more pronounced here than in northern Arizona. So a second group of 6 borings was made December 22, 1921, at higher levels, that is, from 7,500 to 8,700 feet, of which all but one were usable. In this collection I was assisted by Mr. M. S. Lankford. In a recent review it was noted that the Santa Rita tree-records have the intensely small Flagstaff years, 1847, 1902, 1904, and so forth, but are erratic within the group, omissions and change of size making cross-identification very laborious.

Each of the five trees was standardized and the resulting average curve, 1670 to 1921, smoothed by a graphic Hann, as shown from 1750 in figure 4. It resembles both the Flagstaff and the Catalina records. Its minute details confirm the dating of the Catalina specimens, which were at first held in considerable doubt. The cycles are 7.5, 11.2, 14.4 (3, oc. ½), 23.0 (3), and 27.4 (oc. ½). This is distinctly of the Coast type. On the whole, it will not be surprising if these southern island mountains are influenced by some climatic situation distinctly different from the northern Arizona plateau area.

THE ROCKY MOUNTAIN ZONE

YELLOWSTONE GROUP (Y)

This group of five increment-cores of white-barked pine (*Pinus albicaulis*) was collected on August 20, 1920, at the eastern edge of the flat top of Specimen Ridge, west of and opposite the buffalo farm, in northeast Yellowstone Park. The trip was made from Camp Roosevelt with the assistance of Mr. A. G. Whitney. The specimens were cross-identified and dated in 1926. They were measured by Mr. Austin, using the long-plot method. They were standardized and give a record from 1693 to 1919. The curve from 1750, smoothed as usual, and shown herewith in figure 5, does not closely resemble the other Rocky Mountains curves, though its cycles are distinctly of that type. They are 8.5 (3), 10.4, 12.5, 17.1 (3, oc. $\frac{1}{2}$), 25.6, 30.3 (oc. $\frac{1}{2}$). Here we see the 17-year period which is characteristic of this eastern zone.

LARAMIE, WYOMING, GROUP (LW)

This group of four cores, of which three only could be dated, was collected on June 11, 1925, while motoring from Fort Collins, Colorado, to Laramie, Wyoming. At some point not far from the State border the road passes through a slight ravine with pine trees on the steep slopes. The three cores afterwards used were obtained here. A few miles farther on, a very large pine growing in a bleak flat area was bored, but the outer rings were too small for certain dating. These specimens were measured by Mr. Austin, using the long-plot method. The records were each standardized and the curve, 1754 to 1924, was smoothed by graphic Hann, which is shown in figure 5. Though its variations are immense, it closely resembles the typical Pike's Peak curve. Its cycles present the characteristic 17-year period with what are probably some of its variants. The cycles are: 6.3 (2), 8.2 (3), 11.5 (oc. $\frac{1}{2}$), 15.9 (oc. $\frac{1}{2}$), 17.4, 18.2, 19.1 (oc. $\frac{1}{2}$), 25.0 (oc. $\frac{1}{3}$), and 35 (2).

CLEMENTS'S PIKE'S PEAK GROUP (C)

In 1919, Dr. F. E. Clements initiated this study of the Rocky Mountain zone by sending me nine sections of trees from the vicinity of the Alpine Laboratory, which is just south of the Cog Railroad above Manitou, at an elevation of 8,700 feet. He described the location of these trees as follows: Three yellow pines from north of track with a south exposure, three Douglas firs from above cabins with a northerly exposure, and three Engelmann spruce from near the brook, with a northeasterly exposure. These were actually cut and packed by Mr. C. W. Cherry, who later helped me at Tucson for a few months. One of the pines was defective and could not be used, and the remaining eight trees were averaged and plotted in a curve from 1783 to 1919. This was recently Hanned graphically, as shown in

Fig. 5—Rocky Mountain zone, smoothed group curves

figure 5, and gave as cycles: 9.3 (2), 18.8 (2, ½), and 34.8. So much material was obtained subsequently from that area that this group, with its informal treatment, has been retained as a check on the others. Without doubt the Douglas firs could be included with the yellow pines, but the Engelmann spruces should be kept separate. This will appear in the Brook group of Engelmann spruce (BES).

PIKE'S PEAK TIMBERLINE GROUP (PPT)

The first Pike's Peak group was obtained close to the Cog Road near timberline, at an approximate elevation of 11,500 feet. Naturally, the trees were not yellow pine. No. 1, a chip from a dead tree, had to be discarded, but five increment-cores, two in Engelmann spruce and three in fox-tail pine (*Pinus aristata*), proved good specimens. They were readily dated and were measured by Mr. Austin by the long-plot method. Each tree record was standardized and the curve, 1734 to 1919, was smoothed in the usual way. The portion since 1750 is given in figure 5. Its complacent character shows at once, yet it compares exceedingly well with the smoothed curves of groups 3,000 feet lower down the mountain. The cycles are 11.7, 14.0, 20.0, 22.6 (oc. ½ or ⅓), and 37. This group, therefore, does not classify well as of Rocky Mountain type, but its cycles are of the general western sort. One notes here the tendency of the double sunspot cycle to fall a little below 23.0 years; in the Arizona area it was usually a little above.

PIKE'S PEAK BASIN GROUP (PPB)

In making its way east after passing timberline, the Cog Road descends sharply into and then more gradually through a basin area to an outlet in Ruxton Creek, where the water-supply for the cities below is taken. The more level part of the basin has an altitude of about 9,500 feet, and here four borings were taken, of which three (PP 7 to 9) form the basin group. Mr. Austin measured these by the long-plot method. After standardizing, a curve, 1693 to 1919, was drawn and smoothed by graphic Hann; figure 5 gives the part since 1750. This has much larger variations than the timberline group and compares closely with the later groups near the Alpine Laboratory. The unusual feature in this group is the doubling of average growth after 1865. The cycles are 10.2 (2), 13.0 (oc. ½), 20.0 (3, ½), 25.6, and 30.7 (2, oc. ½ or ⅓). The absence of a 17-year cycle is not usual in this zone, but the presence of 25- and 30-year cycles is very characteristic.

UPPER NORTH TRANSECT GROUP (HNT)

The Alpine Laboratory has an elevation of about 8,700 feet, and near it are varying contours well worth testing. The various Pike's Peak groups, including those already described, were originally selected as a study in topography. After leaving the basin the Cog

Road descends sharply, following the bed of Ruxton Creek. The laboratory is situated on a small southern tributary, Jack Creek, just above their confluence. Dr. Clements has made extended ecological studies on a certain area, the Transect, which extends a half mile up the high, wooded slopes to the north and perhaps a third of a mile up the shorter and more barren slopes to the south. The north branch of this transect has very steep slopes in the lower part near this creek and the Cog Road, and gentler slopes above. So the collections there were divided into upper and lower groups. The upper group, PP 11 to 20, has an average altitude of over 9,000 feet and includes 5 yellow pines, 3 Douglas firs, and 2 limber pines. These 10 cores were measured by Mr. Austin, using the long-plot method. They were standardized, and the curve, 1655 to 1919, was smoothed as usual, and the part since 1750 is shown in figure 5. It resembles the neighboring groups very closely indeed. Its cycles are 6.8 (2), 8.6 (2), 9.3, 13, 17.2, 22.6 (2), and 34.5 (2, oc. $\frac{1}{3}$).

LOWER NORTH TRANSECT GROUP (LNT)

The lower group, PP 21 to 27, in the North Transect, was 250 feet below the upper, estimated in vertical height, which makes it about 8,800 feet above sea-level. Mr. Austin measured these cores also by the long-plot method, and the curve, 1644 to 1919, smoothed after standardizing, is shown (after 1750) in figure 5. The result shows a rather even curve, more complacent than the trees farther from the brook. It compares closely with the other group curves. Its cycles are 11.1 (2), 16.0, 20.4 (2), 21.3 (oc. $\frac{1}{2}$), and 40, which approximate but are not exact in their conformity to the Rocky Mountain cycles.

SOUTH TRANSECT GROUP (ST)

South of the Alpine Laboratory the slopes rise abruptly up to some very barren sand areas on Baseball Ridge. A collection of 10 increment-borings was made here with the help of Dr. Gorm Loftfield at an average level perhaps of 8,900 feet. Two of these are yellow pine, 6 are Douglas fir, and 2 are limber pine (*Pinus flexilis*). They cross-identified well and were measured by Mr. Austin and standardized. The curve 1570 to 1919 was smoothed as usual and the result (since 1750) is given in figure 5. It shows vigorous variations which make it probably the best representative curve of this Pike's Peak area. Its cycles also are entirely typical of the Rocky Mountain zone; 9.8 (2), 17.2 (2), 19.7 (3, oc. $\frac{1}{2}$), 25.2 (2), 31.1, and 34 (oc. $\frac{1}{2}$).

BROOK GROUP OF DOUGLAS FIR (BDF)

Ten trees were tested along Ruxton Creek near the Alpine Laboratory, with the purpose of forming a brook group and of learning whether the Engelmann spruce reacts to abundant ground-water in the

same way as the yellow pine and Douglas fir. While dating the records, it was evident that the Engelmann spruce was giving a different story and could not be joined with the firs and pines. So the brook trees are separated into two groups, of which this one is made up of 4 firs and 2 yellow pines. One of these firs, PP–35, carries a dendrograph designed by Dr. D. T. MacDougal. The two yellow pines are only a few feet away, and these three trees are sometimes referred to as the dendrograph group; but they are themselves close to the brook and their records agree well with the other Douglas firs near by, so they make up part of this group. These six cores were measured by Mr. Austin, using the long-plot method, and after standardizing gave a curve from 1782 to 1919, which was smoothed in the usual way and is shown in figure 5. This closely agrees with the other adjacent groups already described, and with them (PPB, HNT, LNT, ST, and C) forms a collection of homogeneous groups which must represent this region exceedingly well. The cycles of the Douglas fir brook group are 7.5, 9.5 (2), 11.4 (oc. ½), 14.3 (oc. ½), 20.4 (2), 22.5 (2, oc. ½), and 39, a good Rocky Mountain set.

BROOK GROUP OF ENGELMANN SPRUCE (BES)

Engelmann spruce growth on the San Francisco Peaks in Arizona had been too complacent for use in climatic study, but on Pike's Peak four trees, PP 28 to 31, along Ruxton Brook, showed attractive variations and even exhibited weak signs of cross-identification among themselves. But when the curves were drawn, it was seen that their growth does not match the growth of the other brook species. The cores were measured by Mr. Austin by the long-plot method and standardizing lines marked on each individual tree-curve by the writer, as always. The resulting smoothed curve, from 1775 to 1919, shown in figure 5, presents marked variations, departing greatly from the typical Pike's Peak curve. Its cycles are 8.9 (2), 12.2 (2), 14.1 (2), 17.6 (½), 24.7 (oc. ½), and 34 (oc. ½). The 17-year cycle is characteristic of the Rocky Mountains, but the presence of a 14-year cycle and a probable sunspot cycle make this set resemble the cycles of the Coast zone.

CLOUDCROFT, NEW MEXICO, GROUP (CC)

Any real representation of the Southwest would be incomplete without specimens from New Mexico's summer resort, Cloudcroft, in the Lincoln National Forest. Accordingly, six good V-cuts from pine stumps were sent me by Mr. Dan Felts, forest ranger there. Three only could be used, and these, as Mr. Felts writes, come from the northwest quarter of the southeast quarter of section 23, township 16 South, range 11 east, New Mexico prime meridian. This is the extreme upper end of Nelson Canyon watershed, half a mile west and

southwest of Russia, New Mexico. Mr. C. W. Cherry measured these specimens by auto-plot method. They were approximately standardized by assigning added weight to the slower-growing trees in forming the averages. The resulting curve from 1736 to 1920, smoothed by a careful geometric Hann and mostly shown in figure 5, presents strong variations which have much in common with the Pike's Peak curves. The cycles are 11.2 (oc. ½), 13.4, 15.3 (2), 17.8, 22.1 (½ or ⅓), 27.5 (½), and 35 (½).

SANTA FE GROUP (SF)

This group was collected on September 5, 1922, with the aid of Mr. B. Z. McCullough, who took me some 4 or 5 miles up the canyon east of Santa Fe, New Mexico. The trees selected had usually a north exposure and were in the general vicinity of the ranger station. They were chosen at considerable height above the brook, so as not to be influenced by it. All of the six cores were readily dated by resemblance to the Flagstaff series. Mr. C. W. Cherry measured these rings by the auto-plot method. After standardizing, he plotted their average in a curve from 1749 to 1921 and smoothed it by a careful geometric Hann. The result given in figure 5 shows excellent variations with distinct apparent similarity to curves of the Flagstaff area, but the cycles conform more to the Rocky Mountain zone, being 10.2, 11.9, 18.4 (2), 22.4, 27.5, and 35 (2, oc. ½). The absence of a 14-year period places it with the Rocky Mountain groups, although the absence of the 17-year period is unusual in that zone.

BASIN MOUNTAIN UPPER GROUP (BMH)

The collection of this and the two following groups is due to the coöperation of the archæologists. In August 1919 I visited the Aztec ruins, New Mexico; thence Mr. Morris took me to Sullivan's saw-mill on Basin Mountain, in Colorado, nearly 40 miles north of Aztec and perhaps 15 southwest of Durango. The mountain has a perfectly flat top about a mile across, covered with pines. The saw-mill is 2 or 3 miles away, in the basin to the east. The pine trees extend down to the mill and a few scattered ones are found even lower down. Two v-cuts were taken from logs at the mill; five more were cut from stumps on the mountain-top before it got dark, and on the way down we cut the three which made the lower group, of which the last was cut by the light of matches long after nightfall. This division into upper and lower groups was made on account of varying water-supply in the soil. The date was August 13, 1919. Mr. J. F. Freeman measured all these specimens by the standard cathetometer method and the seven from the mountain-top have been combined without standardizing to form a curve beginning 1588 and ending 1919, which cross-identifies minutely with the Flagstaff tree-growth.

This curve, smoothed and shown in part in figure 5, distinctly resembles the Flagstaff curves in position of the more prominent maxima, but its cycles, 8.5, 16.8, and 35 (2), are characteristic of the Rocky Mountain zone.

BASIN MOUNTAIN LOWER GROUP (BML)

The three V-cuts in this group were collected August 13, 1919, as has been described in the preceding paragraph. Their actual location was on the upper easterly slopes of Basin Mountain, some 500 feet vertically below the top. Thus climatically they are in the same situation as the others, but with regard to soil moisture they are very different, for they catch a local drainage. In fact, the lowest of the three, No. H–29, had large complacent rings and could not be used. The two remaining ones average 50 per cent larger growth than the upper group. Mr. Freeman measured these with the cathetometer. The curve, not standardized, begins at 1700 and ends 1918. The smoothed curve from 1750 is shown in figure 5. The cycles are 10.5, 11.6, 13.4, 20.4 (oc. ½), 22.7 (3), and 37, which resemble the Coast cycles.

AZTEC EAST GROUP (AE)

On inquiry, Mr. E. H. Morris found that there were Douglas fir trees nearer Aztec than the pines of Basin Mountain, namely, at a point some 20 miles east. Accordingly, early in 1920 he secured four specimens from there, H 39 to 42, which form this group. They showed severe drought effects in several places, which made the dating of the central parts uncertain, and accordingly later in the same year he sent me five more, H 65 to 69, which gave entire certainty to the dating. The earlier four were then measured by Mr. Freeman with a micrometer slide, and the curve, 1662 to 1919, drawn without standardizing (as was the case with several of the early curves) and smoothed, is shown in part in figure 5. As with the others from this region, it resembles the Flagstaff curves. Its cycles are 8.1, 12.4, 19.5, 24.0 (3), and 34.2 (oc. ½), which resemble both the Flagstaff and the Rocky Mountain cycles. A later curve, using all these "Modern H" trees, gives cycles as follows: 8.2, 13.7, 18.8, 20±, 23.8, and 36.

THE COAST ZONE

BOISE, IDAHO, GROUP (BI)

This group is a set of 10 increment-cores sent by the forest supervisor of the Boise National Forest, in July 1923. They came from the southwestern parts of the forested mountains, some 50 miles northwest of the city. The growth is complacent, but the cross-identification of all 10 is good. Two of the trees cross-identify with some of the trees from Klamath Falls, in southern Oregon. These

rings were measured by Mr. Austin, using the long-plot method, and represented dates from 1652 to 1922. The smoothed curve,

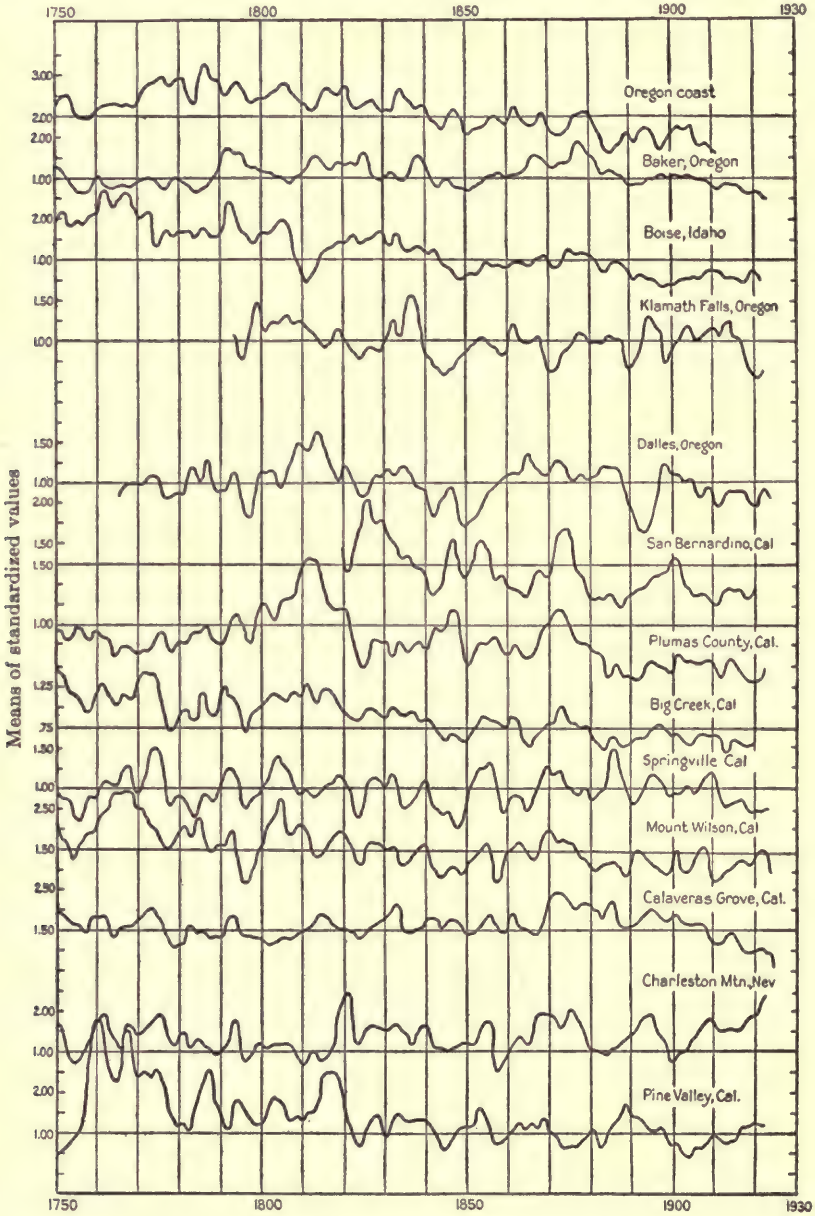

FIG. 6—Coast zone, smoothed group curves

shown in part in figure 6 herewith, when taken in its entire length, and especially when reduced to 3 specimens showing more variation, though complacent for short cycles, evidently has a long period of the order

of 40 years. The cycles are 6.4, 11.6 (3, oc. $\frac{1}{2}$), 17.2 (oc. $\frac{1}{2}$ or $\frac{1}{3}$), 23.0 (oc. $\frac{1}{2}$ or $\frac{1}{3}$), and 36. This strong emphasis on the single sunspot cycle, especially in the higher latitudes, is very characteristic of the Coast cycles.

BAKER, OREGON, GROUP (BO)

The higher parts of the pass between Baker, Oregon, and the Columbia River are pine-covered, and at distances from Baker varying between 60 and 90 miles 8 increment-cores were obtained. These are complacent, and the dating, though probably right, has not the certainty of the Arizona and Rocky Mountain pines. One core had to be omitted because it was erratic, probably from injury. There was some cross-identification with the Boise and the Klamath Falls groups. The rings were measured by Mr. Austin, using the long-plot method. The records were standardized and a curve produced extending from 1660 to 1924. This was smoothed by the usual graphic Hann and is shown in part in figure 6. It is a trifle less complacent than the Boise group and, like it, tends to show a long period of the order of 40 years. The cycles are 6.8, 9.1, 11.3 (2, oc. $\frac{1}{2}$), 15.0, 21.8 (2, oc. $\frac{1}{2}$), and 28.4 (oc. $\frac{1}{2}$). These have some of the Rocky Mountain characteristics.

DALLES GROUP (DL)

The most beautiful part of the Columbia River Highway passes through the mountain range between Portland and The Dalles. On the west side of this range the rainfall is heavy and the vegetation profuse; the east side of the mountains is dry, looking out onto the arid areas of central Oregon. A narrow belt of yellow pine runs north and south along this eastern slope. This small group of three increment-cores came, therefore, from a point 8 miles west of the rapids in the river which gave the name, several hundred feet above the river on its very steep south side. The dating between these three trees was very satisfactory. The rings were measured by Mr. Austin, and the standardized curve from 1765 to 1924 was smoothed in the usual way and is shown in figure 6. This curve has a trace of similarity to those at Baker and Boise, especially in respect to the apparent long period and its phases, but its real conformity is with the California curves to the south. This group shows a profound depression from 1890 to 1894, which suggests fire or injury of some sort. The cycles are 7.2 (2), 12.6, 14.2 (3, oc. $\frac{1}{2}$), 16.4 (2), 18.3, 22.5, and 35.

OREGON COAST GROUP (OC)

This is the group of Douglas fir described in Volume I, which came from the low coast hills 25 miles northwest of Portland, where the rainfall is large and the snows of winter very rare. No real likeness in rings or in smoothed curve (graphic Hann) has been found here to the groups farther inland. The smoothed curve is shown in figure 6.

The cycles are 6.8, 10.2 (2), 14.0 (3), 20.3 (oc. ½ or ⅓), 22.6 (2, oc. ½), and 28.3 (oc. ½). This is of mixed type and does not readily match any one of the three zones. Its 14- and 20-year cycles remind one of Arizona, but the 10-year cycle is strongly Rocky Mountain and the one close to 23 years is most common on the Coast. There is probably some relation between this set of cycles and its position close to the coast.

KLAMATH FALLS GROUP (KF)

This group of 12 increment-cores was received May 12, 1924, through the kindness of Mr. H. B. Rankin, supervisor of the Crater National Forest, near Klamath Falls, Oregon. They had been secured in that forest at an elevation of 5,100 feet above the sea. They cross-identified perfectly, and a few of them show likeness to some of the trees in the Boise and Baker groups. Mr. Austin measured all the specimens, using the long-plot method, and after standardizing, the curve was smoothed by graphic Hann and is given in figure 6. It presents no marked similarity to any other, though the Boise and Baker groups have real touches of likeness. Yet all the while its internal cross-identification was perfect and its smoothed-curve variations look entirely normal. Its cycles are 8.5, 9.6, 14.0, 15.5 (oc. ½), 19.5 (oc. ½), 24.2 (2, oc. ½), and 31.2 (2). This is a mixed set, but perhaps has a little more resemblance to the Arizona area than to the others.

A very fine 500-year pine record was sent me on July 23, 1925. The tree had been cut by the Pelican Bay Lumber Company in the same forest on the southwest quarter of section 35, township 29 south, range 6½ east, W. M., at 5,100 feet elevation and about 5 per cent east slope. This tree does not readily cross-identify with the 12 cores, and as it comes from a different place and is very old, it is reserved for future discussion.

PLUMAS COUNTY GROUP (CP*)

This group of 10 increment-cores from Meadow Valley was sent me by Professor Emanuel Fritz, of the agricultural experiment station, Berkeley, California. He says:

"Meadow Valley is eight miles west of Quincy, and the borings were collected in Township 24 North, Range 8 East. The region is very mountainous, but Meadow Valley is an ancient lake bed. The borings came from the southern border of the valley on a slope, less than 100 feet above the valley floor, elevation 4,000 feet. The water-supply is excellent and the soil is very rich in humus and carries considerable moisture. The forest growth is comparatively luxuriant. All the borings were taken in August, 1922."

They cross-identified well and were measured by Mr. Cherry, using the auto-plot method. They were standardized and smoothed

*"California pines," the first group of that species secured from California.

by graphic Hann. The curve extends from 1551 to 1921 and the part since 1750 is shown in figure 6. It has a distinct similarity to the typical Sierra Nevada curve farther south. Its cycles are 6.7, 11.8, 13.7 (oc. ½), and 28.6 (3), which conforms to the usual ones of the Coast zone.

Professor Fritz also sent a partial section of pine tree from a point at about 5,400 feet altitude in Lassen County, near Susanville. This single tree-record begins at 1588 and ends in 1922. An analysis obtained in the usual way gives as cycles, 16.4 (2, oc. ½), 20.2 (oc. ½), 24.2 (oc. ⅓), and 29.5.

CALAVERAS GROUP OF PINES (CVP)

The collection of this group of increment-cores at the edges of the Calaveras Grove of big trees on July 4, 1924, has been described in a previous chapter, page 53. The additional cores, taken near Murpheys, showed a larger growth average of 1.71 mm. as compared to 1.25 of the trees near the grove, but otherwise appeared to give much the same record, and all were included in one group of 14.

Mr. Hawkins measured these, using the long-plot method. An attempt was made in this group to standardize the individual records by using different gear ratios on the plotting instrument, but it was not felt to be entirely satisfactory, on account of the different average size of different parts of a single record; for instance, the larger central growth in early years of the tree can not be properly allowed for, and yet it is usually too good to discard. The average was undoubtedly improved by this change of gears, and there were so many trees in the group that it did not seem necessary to do any further standardizing. The mean of the 14 trees, 1621 to 1923, smoothed by a graphic Hann, is shown in large part (1750 to 1923) in figure 6. It is at once evident that this belongs to the inner collection of homogeneous Sierra Nevada curves. The cycles in this curve are 6.8 (2), 7.6 (2), 10.4, 14.6 (oc. ½), 21.2 (2), and 30.2, which are of the Arizona type.

BIG CREEK GROUP (BC)

After the sequoia trip of 1919, it was realized that no pine records had been secured in California to aid in the cross-dating between Arizona and California. Accordingly, in 1920, at the request of Mr. Paul Redington, district forester at San Francisco, the ranger on Big Creek very kindly sent me five excellent V-cuts from pine stumps at an elevation of about 5,500 feet on Big Creek, a northern tributary of King's River. This river is just north of the General Grant National Park and the large areas from which the greater part of the sequoia records had come.

These pine specimens cross-identified among themselves exceedingly well, and there was no trouble in recognizing a number of Flag-

staff dates in their rings. The average growth was nearly 50 per cent larger than the Flagstaff growth and many rings were immense. The specimens were measured by Mr. Cherry, using the auto-plot method. They were individually standardized by him and the resulting curve from 1719 to 1919, smoothed by geometric Hann, is shown in part in figure 6. It agrees exceedingly well with the Sierra Nevada collection, which extends from Calaveras Grove to Mount Wilson. The cycles are 8.4, 11.2 (oc. $\frac{1}{2}$), 13.5, 17.4, 21.7 (3), and 35 (oc. $\frac{1}{2}$), which classify as of Coast type.

SPRINGVILLE GROUP OF PINES (EP*)

The visit to Springville in early August 1925, and the collection of sequoia records, has already been described on page 54. The 10 pine borings came from elevations between 5,000 and 6,000 feet, that is, from Camp Lookout to the lower edge of the sequoias, about 4 miles away. Most of the pines had a local south exposure toward a canyon sloping toward the west. Some of these trees were on isolated points, where they could get no possible water except the rain or snow which fell immediately about them. Two could not be used; one was a magnificent 5-foot tree whose growth was too small to allow dating in the core and whose age therefore is probably very great; the other had an extensive fire injury and the rings were too erratic. Mr. Austin measured this group, using the long-plot method. The trees were standardized individually and the curve, 1720 to 1924, smoothed by graphic Hann, is shown (since 1750) in figure 6. It shows excellent variations agreeing most satisfactorily with the other Sierra Nevada curves between Calaveras and Mount Wilson. It is interesting to recall that the sequoias from Calaveras to Springville which show uniform cross-identification, to a considerable extent cross-identify with the pines nearby. The cycles classify in the Coast type as follows: 8.7, 11.4, 13.4 (2), 17.4 (oc. $\frac{1}{2}$), 23.1, 27.6 (2, oc. $\frac{1}{2}$), and 34 (oc. $\frac{1}{3}$).

MOUNT WILSON GROUP (W)

This group of 22 increment-borings, of which 8 are used, was made July 25, 1925, by courtesy of the Toll Roads Company and the Mount Wilson Solar Observatory, who gave permission to bore the trees. The top of the mountain, about 6,000 feet elevation, is a rough semicircle of ridge, convex toward the west and south, with the inner area in the form of an amphitheater of gentle slope toward the central drainage wash, which flows down past Strain's Camp. Sixteen trees were tested in this area, of which 8 are used, all yellow pines except one sugar pine and one Douglas fir, each of which gives apparently the same record as the yellow pines. The 6 Douglas firs tested on the road down the mountain were defective, perhaps in part injured by the road building.

* Elster's pines.

The trees which could be used were in the triangle between the hotel, the Observatory museum, and Strain's Camp. One of the very best, No. 14, is a large tree in the fork of the gulch just above Strain's Camp, close to the upper hall. The ring record of this tree shows strong Flagstaff characteristics. This group was measured by Mr. Erickson, using the long-plot method. The records were standardized and a curve, 1725 to 1924, smoothed by graphic Hann, is mostly shown in figure 6. This curve has strong variations agreeing excellently with the Sierra Nevada curves. The cycles are 7.7, 10.4 (2), 11.2 (oc. $\frac{1}{2}$), 15.2 (oc. $\frac{1}{2}$), 17.1, 22.5 (2, oc. $\frac{1}{2}$ or $\frac{1}{3}$), 29.4, and 34 (2, oc. $\frac{1}{2}$ or $\frac{1}{3}$). These conform to the Coast type.

SAN BERNARDINO GROUP (SB)

The Forest Service in Los Angeles was kind enough to send me in 1922 some 13 increment-cores from the San Bernardino Mountains. Mr. Patterson measured the rings, using the auto-plot method. Five were omitted because they were too short; 2 were reserved because they did not agree well with the others, which formed a real group, and because there was a slight doubt of the dating before 1850; of these one shows an unusually regular 17-year cycle. The remaining 6 were combined into the present group. They were standardized and the curve, 1819 to 1921, smoothed by graphic Hann, is shown in figure 6. The very remarkable 23-year period is the most obvious thing in it. In fact, a search for older trees in that region might give some very interesting and valuable material. This periodic feature stands out because certain maxima which show well in the Sierra Nevadas to the north are here largely suppressed. The maxima which make this curve interesting are all present in the Sierra Nevada curves. The cycles here are 7.7, 9.8 (2), and 22.9 (4), the only case of assigning a weight of 4 to any cycle. These belong to the Coast zone.

CHARLESTON MOUNTAIN GROUP (CH)

The collection of this group of seven cores and one 500-year v-cut on July 18, 1924, has already been described on page 61. Saw Mill Canyon starts just north of the main peak and cuts to the east. The site of these trees is about 7,500 feet elevation and has something like 24 inches of rain. The canyon is narrow and composed largely of gravel terraces. Three trees high up on the very steep terrace bank to the south showed such slow growth that much of their records could not be dated, but the other specimens from the flat canyon bottom gave a fine agreement. The wash was dry. The 500-year stump was close to its north edge. The rings readily cross-identify both with Flagstaff trees and also with Sierra Nevada trees, thus corresponding to the intermediate geographical location. Mr. Hawkins measured them by the long-plot method, effecting partial standardizing by dif-

ferent gears in the measuring instrument. However, each tree-record was subsequently standardized in the usual way and the resulting curve, 1402 to 1923, was smoothed by graphic Hann. The part since 1750 is shown in figure 6. This curve is strongly of the Flagstaff type in the last century or so, except that 1818 to 1821 have large growth instead of small. The cycles are 7.3, 11.4, 14.4 (oc. ½), 17.8 (3), 21.3, 25.9, 29.0, and 34. This is a Coast type.

PINE VALLEY GROUP (PV)

The Pine Valley here referred to is in the mountains some 50 miles east of San Diego, California, at an elevation of over 5,000 feet. The trees are more numerous at the southern end of the 2-mile valley, and of five increment-cores, three come from the vicinity of the summer resort there; one which could not be dated comes from the northern end and one comes from a very large tree about midway. Four were secured in the summer of 1923 and the undated one in August 1925. The rings cross-identify readily with those at Flagstaff. Mr. Hawkins measured the rings, using the auto-plot method. Standardizing was effected by reducing mathematically each tree-record to a set of departures from its own mean. The resulting curve, 1736 to 1923, smoothed as usual, is given in part in figure 6. This curve matches the Charleston group with great exactness and therefore is closely like the Flagstaff-type curve. The cycles are 6.6, 10.1, 14.4, 18.4, 25.2 (oc. ½ or ⅓), 32 (2, oc. ½), and 35, which rather resemble the Arizona cycles.

MISCELLANEOUS GROUPS

The groups mentioned below have been collected for various purposes, but for one reason or another do not lend themselves to the study of cycle distribution. They are added here because reference has been or will be made to them.

SEQUOIAS

Calaveras group (CVS)—This group consists of two increment-cores, three **v**-cuts on fallen trees collected in 1924, and a tracing (recently measured and plotted by Mr. Austin) made by Mr. Manson in the 1880's. This was copied from an original tracing, which, with a separate copy, was filed in the library of the University of California. A copy was loaned to me by the Department of Agriculture of the University of California, and another was sent me by Professor C. F. Marvin, chief of the United States Weather Bureau. This "longitudinal" record is probably from the Dance Hall tree; it goes back to 621 A. D. The specimen which I collected from the "Old Maid" goes back to 525 A. D. My record from the "Father of the Forest" begins at 922 A. D.

Grant Park sequoias (GPS)—This group includes the 21 V-cuts made in 1915 and 1918 in the vicinity of the General Grant National Park. They are described in Volume I.

Topography sequoias (TS)—These are 12 small and usually incomplete radials collected in 1919 from the Grant Park region, giving the last 500 years of sequoia growth and selected with respect to topographic contours, ground-water, and so forth, to get the effect of these features on the size of rings.

Springville sequoias (SS)—These include two numbers, 22 and 23, collected in 1918, and 14 radials secured in 1925 from medium and very old trees at the old Enterprise mill-site some 20 miles east of Springville, California. These will be used especially in the formation of early tree-records and the attempt to date the prehistoric ruins of the Southwest.

COAST REDWOODS

Santa Cruz group (Z)—These are eight radial pieces of coast redwood collected February 20, 1921, some 15 miles north of Santa Cruz, California. These could not be cross-identified and so are not dated.

Scotia group (B)—These are 12 fine radials collected in early July 1925, at Percy J. Brown's lumber-mill, a few miles south of Scotia, California. These, too, did not cross-identify and have never been dated.

ARIZONA GROUPS

Flagstaff century group (FLC)—This includes 10 pines 500 years old, of which one extends back 640 years, all in the vicinity of Flagstaff. These will form the approach to the study of early pine records in the Southwest, which will include many semihistoric beam sections from the Hopi villages, and it is hoped from the prehistoric ruins also.

Flagstaff lava-beds (FLB)—These lava-beds are 16 miles northeast of town. Only two trees belong in this group, FL 48, inside the ring of lava, from which a 1-inch core was taken in 1920, and FL 51, just outside the lava ring, a V-cut from the stump. The former goes back to 1556 and the latter to 1598.

Prescott group (PR)—Nos. 1 to 70 were small incomplete V-cuts sent me by the Forest Service in 1911, described in Volume I. Nos. 71 to 75 are increment-borings made in 1924 to bring the Prescott rain comparison up to date. The records were not intended to go back before 1850, but some of them do.

OTHER WESTERN GROUPS

Pecos, New Mexico (L)—These are four radials from the forest near Pecos, New Mexico, sent by the Forest Service in 1920. They were needed for comparison with the prehistoric beams sent by Dr. A.

V. Kidder, who has been conducting excavations in the ancient ruins there. The rings in these specimens are rather erratic and only one gave a reliable record back to about 1720.

Raton, New Mexico (R)—This is a collection of three increment-borings secured near the highway over Raton Pass. Only one proved datable.

Nebraska (NEB)—This is a group of 12 sections from young trees sent by Mr. Jay Higgins, forest supervisor, at the request of Dr. F. E. Clements, from the plantations on the Nebraska Forest and from the native yellow-pine stands near the Niobrara Division of the forest. The three yellow-pine specimens all cross-identify nicely and give a record extending back to the middle 1880's. The jack pines, except one, are also reliable in dating and extend back to about 1907. The three Scotch pines extend back to about 1913, but do not cross-identify in a way to give confidence.

In the study of western cycles a group from Nebraska would be very valuable, but it should go back 100 years at the least for proper comparison with the other western groups. The above specimens, however, will be most useful in climatic comparisons.

Wind River, Washington (WR)—This group was collected June 20, 1925, at the Wind River Forest Experiment Station, Washington, a most favorable location on a tributary of the Columbia River, perhaps 75 miles from Portland. Five increment-borings were obtained, one yellow pine and the rest Douglas fir. Most of these were erratic in growth, perhaps from injuries, and one, at least, was too much crushed in boring. So the group was not used in the special study of western cycles.

NORTH AMERICAN GROUPS

American Arctic (AA)—These 21 sections, chiefly white pine and fir, came from high latitudes in the MacKenzie River area of northern Canada, by courtesy of Hon. Chas. Camsell and Mr. G. S. Hume, Department of Mines, Ottawa, at the request of Mr. V. Stefansson, the explorer. They were mostly cut in 1923. The interesting and gratifying fact is that they can be cross-identified for the most part and dated. The growth is usually very small and sometimes erratic. The 21 specimens are divided into three subgroups, as follows:

Subgroup	Average age	Average ring-size	Average diameter
	years	*inch*	*inches*
A. Nos. 1 to 6, lat. 60° N., South River group..........	57	0.034	4.08
B. Nos. 7 to 15, lat. 65.5° N., Lake group (Great Bear Lake)	85	.015	2.29
C. Nos. 16 to 21, lat. 66.5° N., North River group......	100	.020	3.94
Total, Nos. 1 to 21..............................	80	.022	3.3

These have been dated, but not yet measured. Considerable parts of all except one can be used, but there is a tendency to show very small compressed growth in the early years. No. 8, the exception, goes back to the neighborhood of 1700, but is too uncertain to use. No. 19 extends to about 1743, but can only be used after 1890. No. 10, beginning about 1792, can probably be measured. A fair record from 1800 will come from the Great Bear Lake region. The South River group extends to about 1835 and the North River group to 1860, with a single one to 1808. This valuable collection will be of the greatest help when the cycles over larger areas are studied.

East Wareham, Massachusetts (EW)—This group consists of some 21 v-cuts and increment-cores secured largely in 1921, from the region between Wareham and Sagamore Beach. The cross-identification is good in most of them, but injuries have affected a number and many are too short and only 8 are held as worth measuring. These will carry a good record to 1840 and a single one to about 1795. This last is from the "lone pine" which used to stand in the lane about half a mile southeast of the Onset Junction railroad station.

Mount Washington group—Two sections of very old black spruce trees from near timberline on Mount Washington have been kindly sent by Professor W. C. O'Kane, of the University of New Hampshire. These grew at about 4,000 feet elevation, were badly deformed, and were some 3 or 4 inches in diameter and about 275 years old. This is the nucleus of a valuable group.

Mount Desert, Maine—Three increment-cores were sent me in 1921.

NW. Pennsylvania group (PA)—This group of 10 v-cuts and 1 increment-core, 10 white pines and 1 beech, was collected May 20, 1922, from the logging camps of the Wheeler Lumber Company, by kindness of the manager, Mr. N. P. Wheeler, jr., in the higher parts of the mountains halfway between Pittsburgh, Pennsylvania, and Buffalo, New York. These cross-identify well and give a record extending back to about 1650. The beech shows favorable ring variation and gives promise of being a useful tree in such studies as these.

FOREIGN GROUPS

Brazil (BZ)—Two 6-foot sections of the South American pine from southern Brazil were measured by the auto-plot method in the Commercial Museum in Philadelphia. They had been cut about 1902 and were each close to 500 years old. They did not cross-identify, though the rings seemed clear and practically without error.

Tasmania (TS)—A section of King William's pine (*Athrataxis selaginoides* Don) from 3,000 feet elevation in the highlands of Tasmania, has been sent me by Mr. G. Weindorfer. It gives great promise of valuable cycle studies in the southern hemisphere.

VIII. ENVIRONMENT

This chapter deals with the effects of climate, topography, and other external agencies on ring-growth in trees; after which the point of view is reversed and the observed effects are listed as indicators of past climates.

EFFECTS IN TREES

CLIMATE

The common factor over large areas is climate. A heavy winter snowfall in Northern Arizona, which supplies abundant moisture for the trees there, extends over hundreds of miles and supplies abundant moisture in northwestern New Mexico, 225 miles away, or over on the coast mountains, a matter of 400 miles in the opposite direction. A dry winter in Flagstaff is usually dry in the other places also. Even at much greater distances the resemblances are enough to enable us to carry dates across in the trees.

Rings a climatic phenomenon—This is not surprising, for the ring is a climatic phenomenon. It begins with large, white rapid growth in the late spring when the sap flows. The usual time of this at Flagstaff (elevation 7,000 feet) is in late May or June and is well observed by the dendrograph, which magnifies the diameter of the trunk and shows its daily and hourly variations. In this arid climate, spring growth depends on the precipitation of the preceding winter, for the months of April, May, and June are exceedingly dry. In July and August come the heavy summer rains with a large run-off and little benefit to the trees. When the season closes, there is a gradual cessation of the activity of the tree, owing to lowered temperature and diminished water-supply. This causes the deposition of harder material in the cell-walls, producing in the pine the dark, hard autumn part of the ring and the protecting bark. The growth stops altogether in winter.

Small single rings—If the winter and spring have been unusually dry, the Arizona tree may stop growing by summer. The resulting ring will consist of a small white spring growth and a threadlike red outside growth. In old trees the ring may become microscopic or appear as a thickening of the red ring of the preceding autumn, and even disappear altogether in parts of the circuit of the trunk. In some extreme cases, sections could be found in which a ring or two is absent from the entire circuit. Very likely it was active for a time but not long enough to leave white cells.

Double rings—On the other hand, if the winter precipitation has been normal, the tree passes through the spring drought and reacts

to the summer rains and displays additional growth. As a rule, near Flagstaff this late growth is very much less in width than the spring growth, usually between 10 and 20 per cent, rarely going to 30 per cent. When it is more than 15 per cent, it begins often to show a double effect, with its central part lighter than the red on each side. In extreme cases this autumn growth actually gets back to the color of spring wood and the growth becomes nearly white, thus separating off an extra red ring that is rarely hard to distinguish from the annual autumn red ring. The distinctive feature is that the false ring fades gradually on both sides, while the true autumn ring fades gradually on the inside but ends abruptly on the outside.

Doubling and locality—The trees near Prescott show an extraordinary number of extra rings, usually easily distinguished by the criterion just mentioned. Some trees there have extra rings unusually small and sharp and separated by very white tissue. Such rings are more difficult to recognize. Sometimes there was more than one false ring. In such cases it is evident that the storm is very important to the tree. At that elevation, 5,200 feet, the rainfall is much less than at Flagstaff, and each rainy season is more nearly a series of isolated storms.

The soil on which these Prescott rings grew is a disintegrated granite which forms a very efficient reservoir, holding abundant water with little leakage. The top of Mount Wilson is very similar in type of soil, though not in climate, for it has a single rainy season in winter. Double rings are practically unknown there. At the lower levels of the Santa Rita Mountains near Tucson the soil and also the climatic conditions are again similar to those at Prescott. The trees there depend on summer rains even more than at the northern mountains and the doubling character is more conspicuous and bothersome. Thus it is seen that doubling is a local climatic effect.

Doubling and age—Doubling is far more conspicuous in the earlier or "youth" rings of a tree when the trunk is rapidly increasing in size. These youth-rings are larger and less sensitive than the later rings. Of course, it is more apparent in large rings, and any tree which grows rapidly is more likely to show it. However, without specially investigating the point, one is inclined to think that young trees, being less sensitive than mature ones, are a little more certain to continue their growth into autumn and so do have more doubling than mature trees. This could be tested by the dendrograph on properly selected trees.

Doubling and summer rains—Since in double rings the space between the false ring and the outside of the real autumn growth is due to summer rains, it seemed possible that this segregated autumn growth might give a measure of the summer rains. This was called

at the time "partial ring study." As far as the matter was carried, the autumn growth was found to be much more closely proportional to the spring growth and to the winter rains than to the summer rains. The matter is one of some complexity, because records of the rains themselves are extremely incomplete, owing to their local and torrential character and heavy run-off. As a result, the tree-records of such rains are local and seem of much less value at the present stage of their interpretation.

Doubles and cycles—In the early Flagstaff work there were two 500-year trees which showed a remarkable half sunspot cycle for nearly 200 years, beginning soon after 1400. One of these was especially perfect in this cycle, showing it with most remarkable regularity (see fig. 17 and Volume I, fig. 32). This tree also was full of double rings. It has suggested the general question as to the character of the record of trees which show many double rings. Is such a record different from those in other trees? So far the answer is thought to be negative, but there is further work to be done on this point.

Doubles and high altitude—As one studies the upper levels of the yellow pine, above 7,000 feet elevation near Flagstaff, the double or extra ring becomes less and less common. So far as tests go, it does not appear at all in the highest trees. In these higher trees the rings are more complacent, there is apt to be less pitch, and so less red color, in the autumn part; yet this autumn part shows a large proportionate size. Here probably the summer rains play less part in the tree's life, for they are too local and the run-off is too big. But the winter snows especially are too heavy, the ground stays moister, and falling temperature is more often the agent which stops the yearly growth.

Other trees—As stated above, the yellow pine in California shows very rare doubling. Douglas firs and sequoias practically never have it, but pinyon and juniper at the lower levels in Arizona are badly subject to it.

Large single rings—If rains in Arizona are abundant and well distributed, growth extends beyond the summer period. A good distribution here does not mean that they assume at all an even distribution, for in many years evident division into wet and dry seasons has never failed. In a long drought the summer and winter rains decrease and the spring and autumn rains disappear, sometimes entirely. In wet periods, summer and winter rains are heavy, and spring and autumn rains come every few weeks. In this latter event the trees carry their growing-season into autumn. Thus, without putting on any preliminary red ring, they show a wide growth of white tissue, ended in autumn by a dense, narrow red ring.

Rings in buried trees—In the vicinity of Flagstaff a considerable number of buried trees have been washed out at depths from 18

inches to 16 or 20 feet. The upper trees have rings of modern type, while the lower ones show enormous rings up to a centimeter in size. They exhibit two characteristics which go with larger water-supply than noted to-day in Arizona. The centers of the white parts of the youth-rings show sometimes a softening that gives an effect almost of an abnormal ring. And when the tree is old the red part of the rings is very massive and wide in proportion to the rest, and the ring sequence is subject to characteristic "surges" which are common in European and other wet-climate trees. In this surging there is considerable difference between largest and smallest rings, but the change from large to small or the reverse is gradual, so that the mean sensitivity is low, though the rings show strong variations. This sort of thing is very different from the habit of the living Arizona trees.

Certain small white needle-shaped crystals discovered in these ancient stumps were identified by Dr. F. N. Guild (1920, 1921) as the first observed occurrence of terpin hydrate as a natural mineral. On account of the location, it was named "Flagstaffite."

RAINFALL CORRELATIONS

If successive years were exactly alike, the rings would all be of the same size, with some alteration with age or injury. But successive years are not alike, and in their differences there are climatic factors which appeal strongly to the tree. In northern Arizona, with its limited moisture and great freedom from pests and with no dense vegetable population, and with the seasonal correlations above described, this controlling factor is unquestionably rainfall. This is entirely in accord with the rainfall comparisons given below.

Prescott growth and rainfall—This was worked out to 1908 in Volume I. Its insertion here is to call attention to figure 7, which gives tree-growth and rainfall at Prescott extended to 1923, with a new calculation of rainfall from growth, using the method described in the previous volume. The discrepancies in the last few years probably arises from the error of boring trees too near the roads, as was the case with the recent collection. The calculations and plotting for these curves were done by Mr. D. A. Hawkins.

Flagstaff tree-records and rainfall—The official Weather Bureau records at Flagstaff began in September 1898. Hence, there are very few years for comparison with tree-growth. A gain has been made by using fragmentary records beginning in 1888 and filling in the deficient months by estimation, using for comparison various records in other localities of northern Arizona, such as Holbrook, Fort Defiance, Prescott, and so forth. Practically all the precipitation after November 1 falls as snow, and hence that date is used as the beginning of the year in reckoning rainfall. But even so the total rain does not show a

correlation with tree-growth. So, remembering that the torrential summer rains do not greatly benefit the trees, the year was divided, as it is naturally, into winter and summer precipitation, the former from November 1 to June 30 and the latter from July 1 to October 31. It was immediately evident that this removed the unexpected disagreement, for the winter values closely resemble the tree-growth, while the summer rains (averaging 10 out of an annual total of 23 inches) show no relation to the growth. This is shown in figure 8. Though the length of record is not great enough to test satisfactorily any formula for reducing rainfall to tree-growth, or the reverse, the evidence indicates that the same principle of accumulated moisture used in the

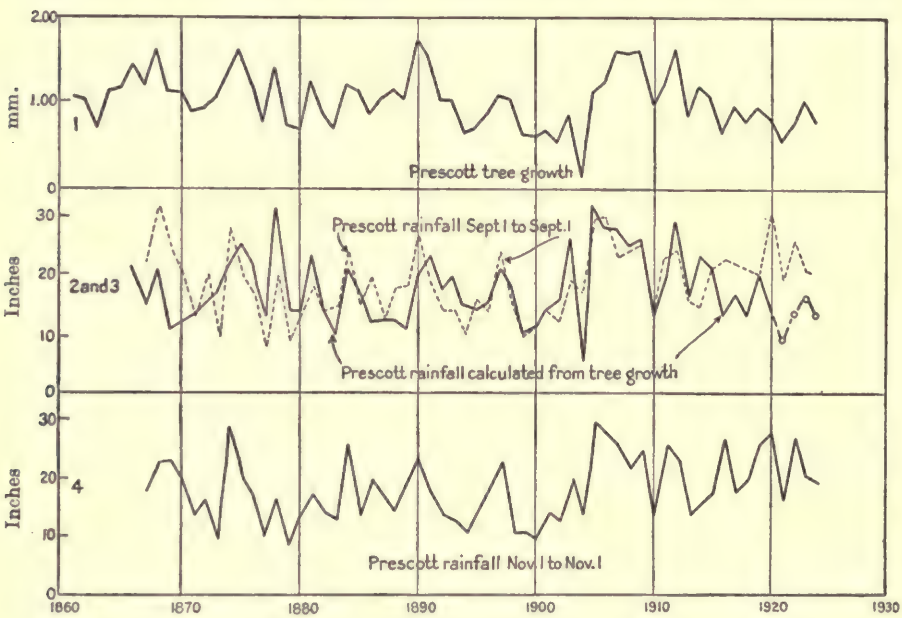

FIG. 7—Prescott rainfall and tree-growth

Prescott correlation (Volume I, p. 66) applies here. The accumulated moisture curve for the winter precipitation at Flagstaff is shown in curve 4 of the figure.

Flagstaff and Prescott difference—In the correlation between rainfall and tree-growth at Prescott, it was not necessary to segregate the winter rains for the purpose, because the correlation was apparent when using the annual total. But in the Flagstaff area the winter precipitation only can be used. Without doubt this difference arises from the topography of the country. Prescott is situated in the lap of the Bradshaw Mountains opening to the north and protected from the southerly summer winds, while the Flagstaff area is mostly on the south side of the lofty San Francisco Mountains, about which summer

clouds gather more easily perhaps than at any other point in Arizona. The summer rains, especially near these mountains, are intense and local and are likely to destroy any correlation.

Arizona-California rain record—There is a further important advantage in using only the winter rainfall, namely, that such precipitation is essentially alike in Arizona and California. Since the coastal region has practically no summer rain to complicate the situation, the trees of Arizona become admirable recorders of California rainfall. In fact, it seems probable that these Arizona trees give a better record of California rainfall than do the California trees, so far

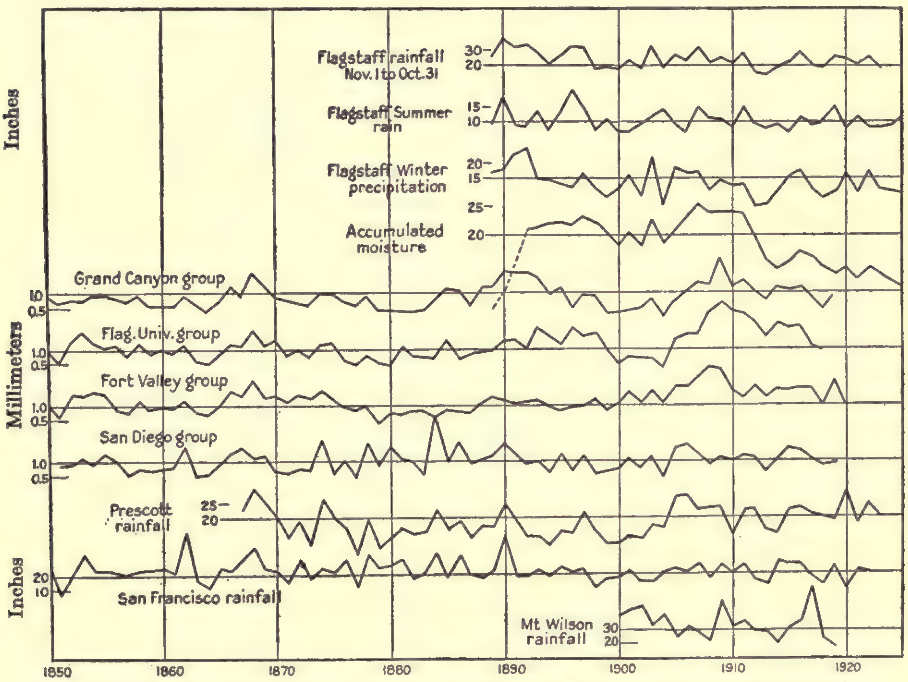

FIG. 8—Flagstaff rainfall and tree-growth, with comparison curves; the tree-growth shows close relation to winter precipitation

discovered, though it is possible that very carefully selected sequoias will be found to give good records. This similarity in rainfall appears in figure 8, where the Flagstaff, Prescott, San Diego, San Francisco, and Mount Wilson rainfall curves are reproduced. From a meteorological point of view the similarity is not surprising, for the winter storms of northern Arizona cover very large areas and come from the coast with very trifling modification, giving precipitation in Arizona about one day later than in California.

Cibecue drought record—Figure 9 shows the record of a single tree, J-3, as measured by the auto-plot method. It shows the droughts between 1870 and 1905 in a striking manner.

Sequoia growth and rainfall—The attempts in the previous volume to find a real correlation between sequoia growth and precipitation (p. 70) were not satisfactory. Figure 10 shows a decided improvement brought about by the high-level trees, D 1–5, corrected for gross rings and compared with rainfall at San Francisco. There seems to be a real

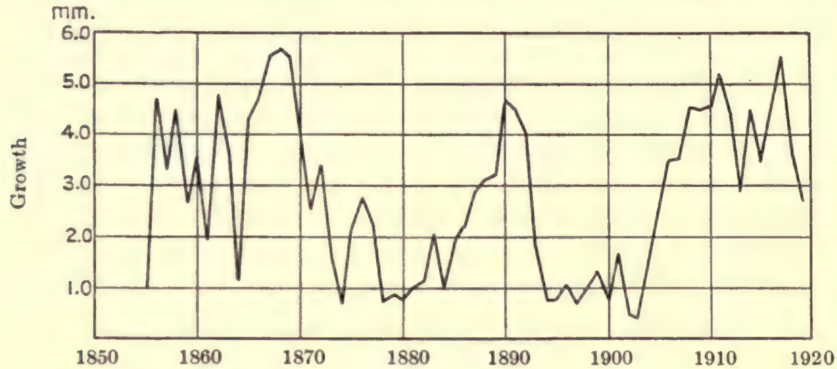

FIG. 9—Cibecue drought record traced directly from autoplot

relationship here, even though it does not yet equal the Prescott correlation.

Comparison records—There is yet much to be done in this comparison between tree-growth and rainfall, but the obstacle everywhere is the lack of rainfall records near the trees and over adequate periods of time. The five Prescott groups showed that in a mountainous country nearness is very important. Until very recently the nearest records to the sequoias were 65 miles away and at an elevation 500

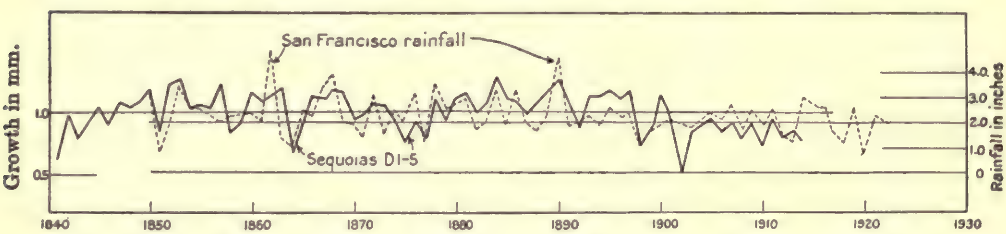

FIG. 10—Sequoia growth and rainfall

feet lower. Colonel John R. White, superintendent of the Sequoia National Park, is greatly to be commended for starting adequate records there.

CONSERVATION

In the Prescott correlation, as discussed in Volume I, a conservation formula was applied, based on the idea that the accumulation of excesses or deficiencies in moisture affect the general activity of the tree. One might say that the trees respond each year to the amount of rainfall, but that their vitality is affected by the

conditions for some years back. Thus, during the dry period from 1870 to 1905 or so, the trees responded each year to the fluctuations in rainfall, but with less and less spirit. This suggested that the conservation was in the tree itself.

Reversed conservation—In considering the details of smoothing curves of tree-growth (page 44), it seemed as if the derived value should substitute for the last of the several used in getting it, but as a matter of fact there appeared to be better agreement with rainfall when the derived value was placed in the middle, as in the graphic Hann, used so much in the western groups. This could only be true if favorable years affect the preceding year as well as the one after. And in the growth of trees that is not impossible, so far as we know at present, as will appear in the next topic.

Possible change in ring-size—The sapwood commonly holds much reserve moisture which can without doubt be drawn on for the needs of the tree and whose depletion can be changed to abundance when conditions are favorable. It may be that the conservation or vitality of the tree lies in this storage capacity. If so, it is entirely conceivable that the moisture condition of the growing layer affects the actual size of the rings near it, and that the ring-size is not absolutely fixed for several years after its growth. A first attempt to test this matter by borings in the same tree (FL-90) at 4-year intervals was not satisfactory, because the cores happened to show some slight irregularities in growth and were allowed to dry before measurement. Such variations as are referred to here might show in the dendrograph.*

Water-soaked rings—As an illustration of probable change in ring-size in dead trees from excessive water-content, reference is here made to the tests on a fallen sequoia described on page 24.

Repeated use of rain—Somewhat connected with the subject of conservation is the matter of the repeated use of rain. In separating the rainfall at Prescott into winter and summer records, the cycles of the winter rains at Prescott seem to be repeated in the summer rains, but the important ones in the summer rains do not carry over to the winter. This seems to mean that winter moisture lasts over locally to summer, but summer moisture mostly runs off or evaporates. This difference comes from the different types of storms in winter and summer. In the former, the storms come from the coast and clouds are continuous over an immense area. There is no chance for evaporation of any amount. On the other hand, in summer the sun is very powerful and each morning promotes evaporation over large areas between the scattered clouds. Storms come from the south and con-

*Since the above was written, Dr. MacDougal has told me that he has detected with the dendrograph certain changes in the thickness of the two or three outer annual rings, depending on the temporary condition of the moisture-supply.

sist of immense masses of warm air laden with moisture. When these pass over a large mountain, they are thrust up in the air and start the storm. When there is not enough motion in the air to draw in distant moisture, clouds form directly over the valley, evidently composed of moisture from the valley. As the day goes on and the air gets a general motion, these clouds are carried forward and contribute to the rainfall in adjoining localities.*

OTHER CLIMATIC CORRELATIONS

Several factors may enter into the tree-rings at the same time; for example, rainfall, temperature, length of growing-season, and direct solar stimulation. These may be isolated in two ways. We may select and study a special region, as northern Arizona, where nature has chosen out some one factor and made it preëminent, as rainfall. Or we may isolate certain relationships as in any other investigations, by using large numbers of observations, that is, many trees, and averaging them with respect to one or another characteristic.

Temperature—Undoubtedly temperature and the resulting length of growing-season enter tree-growth. At high elevations this becomes the controlling factor. Probably that is the reason the Upper Flagstaff group, FLH, shows departures from the usual curve of that area. But there is no evidence that temperatures affect the lower pine growth to any important degree, nor the sequoia growth, especially in the southern groves, for sequoias at the highest and coldest levels promptly respond to increased water-supply by enlarged growth, as in the case of D–31, referred to below in connection with sequoia topography.

Wind—Reinforced rings (see page 32) are interpreted as due to wind or other pressure exerted in a constant direction. In the prehistoric material from the ruins northeast of Flagstaff, such rings rather plainly indicate exceedingly strong spring gales from the west or southwest, if we can judge by conditions at the present day.

TOPOGRAPHY

The broad effects of topography were encountered and recognized in large measure while searching for the oldest sequoias. Almost at the start it was realized that size is far from a final indication of age, for nearness of water alters the rate of growth profoundly; for example, it is possible to assign 2,500 years as the approximate time it took the General Grant tree, which has no running water near it, to reach its present immense diameter of close to 30 feet. But about 3 miles west, near a running brook, is a stump which is over 25 feet in diam-

*In Tucson we have perfectly clear views of the Santa Rita Mountains 40 miles south and 7,000 feet higher than the city, the Rincons 20 miles east, the Catalinas 20 miles north, also close to 7,000 feet higher, the Casa Grande and other mountains 50 miles northwest, and the Tucsons, 15 miles west, and so on. Cloud formations are easily seen.

eter, but is only about 1,500 years old. That rapid growth is the effect of contact with an unfailing source of water.

SEQUOIA TOPOGRAPHY

In selecting specimens to settle a dating problem, in 1919, preference was given to trees at such distance from the obvious water-supply that the specific dependence of trees on the nearby brook could be tested. Thus from Redwood Basin, 15 miles east of the General Grant Park, a total group of 21 sequoias was obtained. The trees were scattered for a mile along this valley, whose slope faced the north. The upper or southern end is near the top of the mountain, but a spring supplies a small stream of water. The upper trees mostly had a very dry soil, while those below, some 600 or 700 feet in vertical measurement, had more level ground and greatly increased moisture. The average growth per century in the last 500 years was about 7.6 cm. The least was less than 4 cm. and the greatest was over 15 cm. The fast-growing trees were mostly close to the water-course in the lower basin. The average growers were mostly around the edges of the basin, while the slow-growing trees were chiefly at the tops of the slopes. Three larger growing trees close to the upper limit formed interesting exceptions. One was a youthful sequoia, only 700 years old when cut, and therefore naturally a fast-growing tree. Another at the very highest point was about 50 yards above the spring and undoubtedly tapped an underground flow of water leading to it. Its type of rings was very similar to those in the basin. The third exception had very large rings, but they were full of sensitive variations like the slow-growing trees nearby. This tree is probably over a pocket of water whose help increased its growth, but which failed in extremely dry conditions. It is evident, then, that with the sequoias moisture may control the growth up to a maximum fully four times as large as the minimum.

Ring-type and moisture—The type of ring and its adaptation to identification and study varies greatly with the moisture-supply. The large rings of the quick-growing trees are either very complacent, that is, of the same size for many years in succession, or gross in character, which means extraordinarily large rings here and there; and their whole grouping is apparently subject to slow surges in size as one glances across the sequence from center to bark. Gross rings in one tree have about an equal chance of appearing or not appearing in any other tree near by. Since gross and complacent rings have little individuality, it is not always easy to identify their dates, especially if the outer layers of wood have been cut away, as was usually done in felling the sequoias. On the other hand, the slow-growing, low-moisture trees are full of irregularities which may be recognized in tree after tree, thus rendering accurate dating a remarkably easy

process. It is also immediately evident that these latter sensitive trees give short-period variations far more accurately and effectively than the complacent trees. These types, as well as the following one, are illustrated in Plate 3 and figure 3. Yellow pines in the dry climate of Arizona at so low an altitude that they have the utmost difficulty in getting water to prolong life become extraordinarily sensitive. In the same tree one finds some rings several millimeters across and others microscopic in size or even absent.

Mean sensitivity—Mean sensitivity, which expresses this different quality in the trees (page 29) depends in large part on the relative

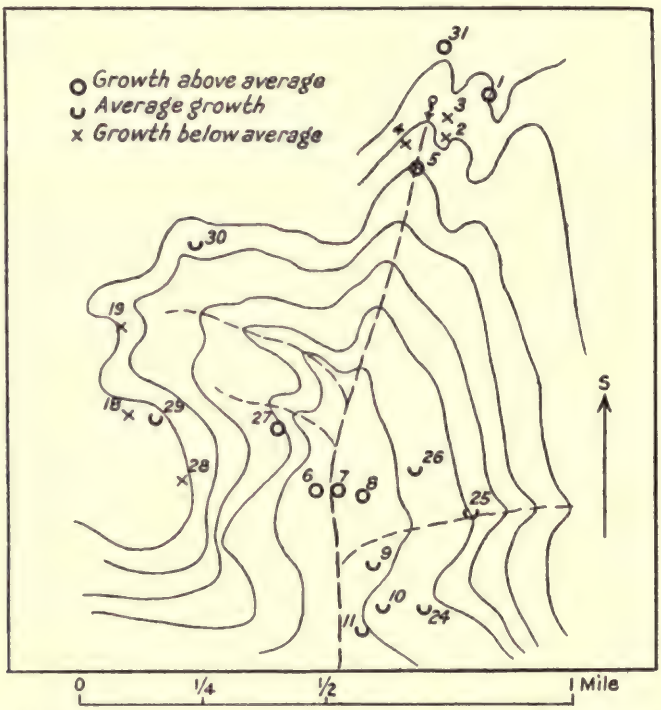

FIG. 11—Land contours and annual growth of sequoias in Redwood Basin

response of trees to climatic influence and so long as there are no large changes of ring-size due to injury, it gives a good criterion of climatic effects in trees. Such appears to be the meaning of figure 12, in which the 10 Prescott trees used in the original rain comparison are plotted with respect to ring-size and other features, including calculated mean sensitivity. The first curve shows them arranged in order of ring-size. The second curve, apparent mean sensitivity, estimated by inspection only, shows that such estimates may be too much affected by ring-size to be of value. Curve 3 shows that sensitivity is independent of ring-size. Curve 5 shows that correlation with rainfall had a slight

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A. Sequoia topography, ridges; area of D–1, 2, 3, 4, 5, 18, 19, 28, 29 and 30

B. Sequoia topography, basins; area of D–6, 7, 8, 9, 10, 11 and 27

tendency to improve in smaller rings, and assuming some error in tree No. 69, mean sensitivity is an excellent indicator of a tree's accuracy in recording rainfall. Curve 4 hints that visual comparison between curves of rainfall and tree-growth was not very different from a mathematical correlation test.

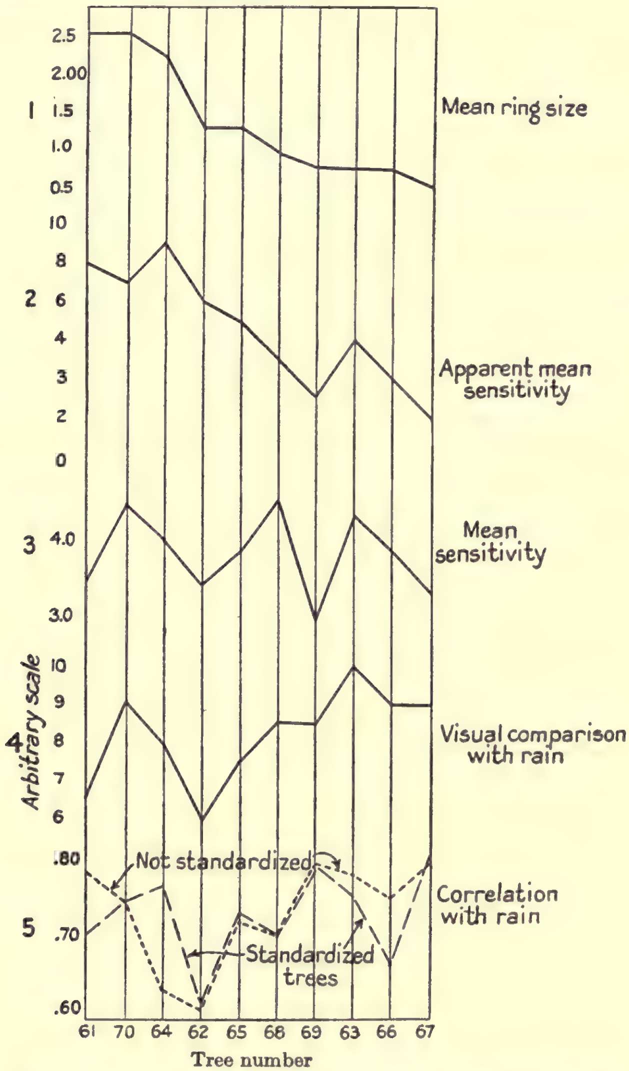


FIG. 12—Ring-size, sensitivity, and rainfall correlations, Prescott

Sequoia contours and cycle lag—Variations in the smoothed curves are much greater on the ridges than in the basins, where the water-supply is far more abundant. The complacent basin curves smooth out the shorter variations. A lag in the basin trees might be expected, since the water takes time in getting there from the higher

surroundings. This has been sought by comparative analyses of basin and ridge trees. A lag of 3 years or more could have been detected, but none was found. There may, of course, be a shorter one.

PIKE'S PEAK TOPOGRAPHY

Pike's Peak contours—In collecting 47 specimens from the vicinity of the Cog Road on Pike's Peak in 1920, locations of test trees were selected with reference to contour and water-supply. The region lends itself exceedingly well to such tests. The valley bottoms are v-shaped rather than rounded, as in the sequoia basins. The sides of the valleys extend for great distances at a somewhat even slope. Water is far less abundant and the trees are left more to their own resources, as it were. The trees are scattered generally and one can get north and south exposures, stream contact, and other features. The soil material is relatively homogeneous compared to the Flagstaff region, where transition is abrupt from limestone to lava or the reverse, and hence tests are impeded on this account. However, on Pike's Peak the same tree does not cover all the conditions tested, and so each must be taken separately.

Yellow pines—Four groups had yellow pines in them, as follows, in order from north to south: Upper North Transect, 5; Lower North Transect, 2; Brook, 2; South Transect, 2. The mean ring-sizes in order were, 1.26, 1.60 (variable), 1.74, and 0.81 mm. The first and second of these showed considerable internal variation. The trees on gentler slopes or in small side-gullies had the larger mean growth, while trees on the very steep slopes toward Ruxton Creek had very slow growth. The largest growth was near Jack Brook, the two yellow pines there being some 20 feet above the water (and near the dendrograph tree). The smallest growth was on the South Transect, with its ridge topography, very steep slope, and sand areas indicating dryness.

The south-exposed North Transect, near the foot of a long mountain slope, has growth 75 per cent greater, and the brook has growth 100 per cent greater than the South Transect, which extends nearly to the top of a low, dry ridge. The extra brook growth is obviously a question of water-supply. So we infer that the added growth on the North Transect is due to moisture-supply also, and from the similarity to the Flagstaff area in some prominent features of the tree record, this better moisture-supply comes in the snows of winter. This has been considered in some detail, because the Douglas firs next considered give similar results.

Douglas firs—Douglas firs occur also in the same four groups: Upper North Transect, 3; Lower North Transect, 3; Brook, 4; and South Transect, 6. The respective mean growths are 1.09, 0.99, 1.20,

and 0.43 mm. The apparent strong effect of slope in different parts of the North Transect appears again here and emphasizes the value of further work directly on that point. The growth on the North Transect is 142 per cent greater and at the brook 179 per cent greater than on the South Transect, and the same inference prevails as with the yellow pines.

Limber pine—Limber pine (*Pinus flexilis*) occurs in the three transect groups and the basin group at 9,500 feet. Three trees in the basin have a mean ring-size of 0.69 mm. The others of two trees each have 0.93, 1.02 (variable), and 1.00 mm. (variable). Thus, we can not make conclusions from the data on this tree, except that the reduced growth in the basin, 9,500 feet elevation, is very likely a result of temperature.

Engelmann spruce—Two specimens of this tree in the timberline group, 11,500 feet, give a growth of 0.95 mm., and four specimens at the brook give 1.16 mm. This difference is quite as likely to be temperature as moisture.

Fox-tail pine—Three trees of this species, *Pinus aristata,* were included in the timberline group, with an average growth of 0.63 mm.

Age correction—No age correction has been used in these figures, but as the selection of trees uniformly favored the larger and older ones, it is not likely that such correction would materially alter the results.

Summary—The area tested on Pike's Peak lies on the east slopes, chiefly below the basin. The pines and Douglas firs here show evidence that water is the prominent controlling factor, the pines having somewhat larger growth than the firs. The limber pines tested had an average growth between the other two, but were variable and, except that they give the same tree records as the others, there was no decisive material regarding their sensitiveness to moisture-supply. A single group of fox-tail pine gives a similar curve. Engelmann spruce had a larger growth at the brook, 8,700 feet, than at timberline, 11,500 feet, and its ring record is far different from the other species tested. Nearness to running water greatly increases growth in all the species, and apparently in the yellow pines and firs does not interfere with their success as climatic recorders.

SAN FRANCISCO PEAKS AREA

These beautiful peaks, 12,760 feet high, 10 miles north of Flagstaff, have the rounded mass of an ancient volcanic cone, with the huge outlying spread of Elden Mountain (9,000 feet) stretching off to the southeast. They are surrounded by pine forest for miles in every direction and give favorable opportunity for certain tests.

Altitude effect—Two groups, all yellow pines, may be compared to get an idea of this effect, namely, Fort Valley, at an elevation

of 7,300 feet, at the southwest base of the mountain, and Flagstaff High group, at 9,000 feet, directly up that same southwestern slope. The first effect of altitude is an increase of mean ring-size from 1.10 mm. to 1.95 mm. resulting without doubt from the increase of precipitation at the higher point. The rings themselves of the higher group appear far more complacent, but can be dated in terms of the Flagstaff series. In comparing the smoothed curves of the two groups, the variations (those which become conspicuous in the cycle plots) decrease from 34 per cent at Fort Valley to 25 per cent in the upper location, and at the higher point lose much of their resemblance to the other smoothed curves of that region. On comparing the cycles one finds at the upper station the 17.3-year length, which is very rare in the Arizona area. It is more common in the Rockies and on the northern coast.

Shadow—As previously explained, mountain shadow is an expression which here refers to the side of the mountain away from the direction from which storms usually approach. It is, of course, on the east side of the San Francisco Peaks, since the winter storms come from the west and southwest. Two groups were taken to the east and northeast of the peaks; the shadow group (SH) close in at the foot of the steep eastern slopes at about the same level as Fort Valley, and Flagstaff Northeast group (NE), about 7 miles farther out from the mountain center and at the edge of the pines at an elevation some 500 feet lower. The ring-sizes in the SH group is 1.52 mm. and in the NE group 1.17 mm. The cycle variations of the former are about the same as FV (34 per cent), but the corresponding variations of NE are near 70 per cent. On examining the smoothed curves each seems to be free from short interfering cycles, and perhaps this is its special quality. The difference between them appears to be a question of water-supply, which is abundant very close to the mountain, but rapidly decreases to the east. This same characteristic of relative freedom from short-period cycles appears in the Lower Rim and the Cibecue groups and in the Charleston Mountain group.

Soil and bed-rock—Many of the Flagstaff groups grew on soil that was not distinctive. The first, for instance, was on deep soil formed by an outwash fan from Woody Mountain, which is igneous rock. The 500-year trees of FLU grew on a considerable soil over limestone. Probably the old group at Lake Mary, whose curve is given in Volume I, page 26, illustrates best the effect of this limestone soil. Its mean ring-size is about 0.75 mm. It shows rather stronger variations than the FL curve. For comparison, a group of two trees at the Lava Beds, 15 miles northeast of town, may be quoted. These trees were about 350 years old and show large growth when the trees were small and then a very long continuance of uniform small growth (0.50 mm. in one and 0.75 in the other), with slight variation. Lava

soil of this sort is full of clay which is formed by decomposition of the rock. It is therefore water-tight compared to limestone soils. Hence, moisture caught in the former stays in place and produces a uniform tree-growth, while moisture entering the limestone soils readily passes away from the roots. The growth over limestone has larger percentage variations with better climatic relationship. This confirms the reference to this topic in Volume I, page 22.

Soil-moisture gradient—It is possible that a criterion of this difference could be found by the vertical soil-moisture gradient. Certain species of pine can grow in very wet land. In such cases the soil is wet at the surface, then soaked, and then full of water as one goes down a few feet. Tree sections occasionally appear which show an enormous increase in growth on draining such land. At an eastern point (Cape Cod, Massachusetts) the surface soil near the pine trees is sandy and below that are moist glacier gravels, down to water at 20 feet. In contrast with this, the trees around Flagstaff grow mostly on a thin layer of soil, perhaps 2 to 10 feet, upon impervious, igneous rocks, or upon porous and cracked limestone. Over the igneous rock is often a layer of clay. During a large part of the year one may dig about the tree, or near the tree, and find the ground apparently dry. Clays and volcanic rocks hold layers of moisture for a considerable time, but the soil over the limestone, as observed in some cases, gets drier and drier as one goes down. The average soil-moisture gradient, therefore, seems promising as a help in determining certain controlling factors in tree-growth.

Root conditions—Mr. G. A. Pearson, director of the Southwestern Experiment Station, has very kindly supplied data regarding depth of the root systems under certain trees near Flagstaff and per cent of available soil-moisture, as follows: The greatest depth attained by tree roots is usually around 4 feet, but only a few of them reach this depth; the great masses of roots are found in the upper 2 feet. In the case of spruce, very few roots are found below 1 foot in depth. These measures cover the woodland (cedar), yellow pine, Douglas fir, and Engelmann spruce. In his bulletin entitled "Natural Reproduction of Western Yellow Pine," a series of graphs shows the available soil-moisture in per cent of dry weight of soil, for the summer months, including May to September. At 6 inches in depth the amount for cedar and yellow pine varies from 1 to 9 per cent, and for the other trees about twice as much. At 12 and 24 inches of depth the amount for pines and cedars is between 5 and 0 per cent, and for the other trees about twice as much. The precipitation curves during the same seasons, 1918 and 1919, show that rainfall in the preceding months is felt by these trees at 6 inches, and by the high-level trees, fir and spruce, at 12 inches of depth, for at such levels the rainfall is greater, but at 2 feet only the Douglas fir shows it.

CHANGING CONDITIONS

The preceding topographic conditions are constant and their effects are sought by comparing trees in one location with those in another. The results are practically constant in any one tree. But changing conditions produce internal alterations in each tree and may often be recognized in the ring record after allowing for the normal change of ring appearance with age.

Shade—The Vermont hemlocks from the edge of Mount Ascutney, near Windsor, showed a doubling of yearly growth about 1808, due probably to cutting of adjacent trees at that time (Volume I, pages 41, 42).

Drainage—A small section of Scotch pine in the Berlin Museum shows minute rings for some 40 years and then suddenly the growth is quadrupled. As the history of the tree showed, this was caused by draining the very wet land on which it grew.

Soil deficiency—A very interesting relationship was recognized by studies in Chaco Canyon in 1926. For 10 years it had been noticed that certain prehistoric or early historic trees showed normal growth to a very good size and then rather quickly the growth dwindled down to a great number of microscopic compressed rings from which there was no recovery. In human language, the tree starved to death. Some of these specimens came from Chaco Canyon and a number came in 1926 from Wupatki, a ruin 35 miles northeast of Flagstaff, in the region of the Lava Beds and volcanic cinders, which suggested showers of volcanic ashes as a means of killing forests. But on the bare rock mesas about Chaco a few pines were found in favorable spots where a little soil covered the bed-rock. Some were dying, some dead, and a very few in good condition, but most of them showed the compressed rings for the last 50 or 100 years. Evidently there was enough soil for small trees, but not enough to support full-grown trees, and the shallow beds of soil were drying out and in many cases blowing away. One small pine in bad condition had 2 feet of horizontal roots bare before any of them were covered by soil. This lack of soil and change in its condition, then, is the common cause of that sort of outer compressed rings in this arid area.

Close grouping—A test for the effect of close grouping of trees was made on the Fort Valley group. These effects have already been described in connection with tree selection, page 12, and eccentricity of ring-growth, page 22.

Injuries—The injuries chiefly recognized in the western groups are fire and lightning-scars, already referred to in the selection of trees, page 14.

Pests—This topic is a recognition that such effects are of great importance in the general consideration of tree-rings. Where moisture

and sunlight are abundant and vegetation is densely crowded and competition is intense, as in wet-climate forests, many individuals must perish, and pests are largely the agent. Climatic conditions influence these pests and we find therefore climatic variations in the trees injured by them, but such effects are apt to be more hidden and less clear and direct than in the dry Southwest, where the trees are isolated and rainfall is the controlling factor. Pests, of course, attack the trees in different ways, but when the growth is seriously interfered with the rings show diminished size and may disappear, and abnormal growths may enter.

ENVIRONMENT INDICATORS

The preceding pages of this chapter have dealt with the effects in tree-rings of various exterior forces; the present paragraphs are intended as a brief introduction to the general reversal of this process, namely, estimation of exterior conditions by internal evidence in the trees. So far as rainfall is concerned this is not new, for most of the work done by the writer has had that purpose as its central theme. But in approaching the study of prehistoric and geologic material, the general consideration of all information contained in the rings becomes more and more important. So long as one can apply the principles of cross-identification, it is easy to isolate the climatic effects, for climatic effects prevail over large areas for a short time, while topographic influences modify the growth-rates in small areas more or less permanently. Thus, as the use of groups of trees becomes less and less possible in studying climates more and more remote, the separation of climatic from topographic features requires notice to be taken of all indicators of environment found in the trees. Without any pretension to completeness, the following classification paves the way to a future study of this interesting subject.

EVIDENCE IN INDIVIDUAL RINGS

This varies in different species, but in the yellow pine a widely double ring means a double rainy season, especially if habitually recurring. Narrow and indistinct doubles and multiples probably mean the same, but in the extreme, multiple rings may refer merely to individual storms.

Average ring-size—This reflects water-supply, which consists (1) of rainfall modified by continent, mountain ranges, latitude, and altitude; (2) of ground-water, or secondary rainfall, modified by drainage contours and kind of soil.

EVIDENCE IN SINGLE TREES

Ring-type—Ring-types are: (1) complacent, meaning reasonably sure water each year; (2) complacent surges, meaning some slow

variation in the complacent type; (3) sensitive, meaning limited water-supply from lessened rainfall and greatly diminished ground-water; (4) shadow or sensitive surges, meaning very great variations in slow-growing trees, such as come near the lower (dry) margin of the forest; and (5) erratic, meaning immense variations in water-supply, causing some rings to be omitted, while others are very large.

Missing rings—This occurs more often in old age of the trees and on very dry ridges, where the moisture is not likely to stay in the ground nearby.

Merging rings—These occur in the pines in dry periods. It does not usually mean close grouping. It occurs normally in the junipers and pinyons without close grouping. It probably does not usually mean close grouping in the big sequoias, but in coast redwood it does indicate it.

Gross rings—Gross rings in the sequoias are understood to mean root success with a slight climatic relationship, and to point toward certain variable conditions of grouping.

Lightning scars—Lightning scars are easily recognized in the tree section, but not in the core. They are climatic and occur in torrential summer-type storms.

Fire injury—This also is easily recognized in the section. Such fires are usually started by lightning and so become climatic in interpretation.

CHANGING RING-SIZE

The change with age is always conspicuous in the diminishing size from center to back. Rings growing smaller and then larger to a marked degree, in Arizona, mean drought. Badly compressed outside rings mean shallow and perhaps denuded soil. Probably soil denudation is better indicated when the compression lasts 50 or 100 years. Drainage of soil and relief from too much shade are of rare occurrence, but when they do come, are recognized by a very considerable change that is fairly quick and practically permanent. Reinforced rings mean wind whose season of occurrence may sometimes be estimated.

Climatic variations—Outside the various effects mentioned above, the further variations from year to year are mostly climatic. If several trees over some area can be cross-identified, it helps in the climatic interpretation. But the normal average tree in all ages, judged from large numbers of prehistoric beams and many fossils examined and measured, is practically free from other disturbances, and most of its variations, apart from age changes, can be taken as climatic. So also the smoothed curve and its cycle analysis tell a story of climatic variations.

IX. CYCLES

CYCLE ORIGINS

It is now generally recognized that certain small climatic variations are caused by changes in the sun. The study of tree-growth in this volume, and especially its correlation with solar cycles described in this chapter, provide the motive for seeking in the sun the real origin of larger climatic cycles and in the trees a detailed history of the effects of such cycles on organic life.

SOLAR THEORY*

Nature of sunspots—The work at the Mount Wilson Solar Observatory and elsewhere shows that two-thirds of the sunspot groups are dual, with a leader and follower in the direction of daily rotation. These are connected below the apparent surface of the sun and form the two exposed ends of a partial vortex-ring. The brilliant work of Hale has shown that during the recent sunspot cycles the leaders in the north and south hemispheres have exhibited opposite magnetic polarity and that during the two minima under observation, 1913 and 1923, the polarity reversed between the two hemispheres. This suggests a double sunspot cycle as the fundamental period. Hale (1926 to 1927) finds evidence that this polarity results from direction of rotation in the lower parts of the spot. Lighter gases in the upper and thinner layers of the solar atmosphere are sucked downward into the spot. Their direction of rotation resembles usually the rotation of storms on the earth and so is independent of sunspot minimum.

Periodicity theories—No recent advance has been made in explaining the periodicity of sunspots. The weight of evidence favors internal causes; for example, the polarity phenomenon and the "butterfly" diagram (by Maunder; it refers to the continued decrease in mean latitude of sunspots, as each cycle begins, reaches maximum, and ends) both point to internal causes. The possible extension of solar cycles back into geologic ages is more agreeable with an internal cause than with a meteoric hypothesis, using a swarm subject to perturbations and possible dissipation. On the other hand, there is a possibility that several cycles will need explanation, and it is hard to think of several mechanical pulsations in the sun going on at the same time. Mechanical disturbance between a dense core and a lighter shell have been the foundation of some thought on this subject. Snyder and others have been at work on a theory involving atomic energy. This might be called chemical pulsation.

*Continuing a related topic in Vol. I, p. 84.

Turner's meteor-swarm theory has the merit of simplicity, since it merely becomes an extension of the accretion hypothesis (Chamberlin and Moulton) and offers many choices in periods. Perhaps size and shape of a meteor swarm could be invoked to explain crudely the butterfly diagram, but it is exceedingly difficult to reach with this theory the polarity and rotation of spots.

Short-period cycles in sunspots—An analysis of monthly sunspot numbers since 1750 gave a number of possible cycles, of which 7.9 months and especially 10.5 months were the best. The former of these is the period required by a meteor swarm to pass in a very elliptical orbit out to the orbit of Mars and back to the sun. The latter is the period a swarm would have with aphelion near the inner asteroids. The various periods noted in monthly sunspot numbers were found to be multiples of 35 days, which is very nearly the sidereal time of polar rotation of the sun (Abbot, 1925, p. 100). But to the present time no one has found any satisfactory evidence of planetary influence in the formation of sunspots, and this coincidence may be accidental. If there were a tidal effect from any planet, it would presumably take place twice in the solar rotation.

Solar rotation—Adams and others have applied the spectroscope to solar rotation at different latitudes and find sidereal periods for average surface rotation as follows: latitude 0°, 24.6 days; 30°, 26.3 days; 60°, 31.2 days; 80°, 35.3 days. High levels in the solar atmosphere rotate faster at all latitudes.

Radiation—Abbot (1925) has done important work upon radiation, and now has an accurate record of the solar constant from 1918 on. The values passed below normal in 1922 and stayed so during the sunspot minimum of 1923. With the beginning of the new sunspot cycle this constant has come back to normal. All this change seems to be a correlation with the sunspot cycle, with radiation 3 per cent above normal at the maximum activity. However, this is subject to sudden brief decreases, reaching even 10 per cent, when unusually large spot-groups are about one day past the sun's central meridian.

Ultra-violet radiation—Pettit and Nicholson (1926) have constructed a recorder of ultra-violet radiation (which has a powerful effect on plant life), using a thin silver film as screen and producing galvanometer deflections by a thermo-couple. The variations follow the sunspot activity with accuracy and at the same time exhibit a far greater sensitiveness to its changes than found in the solar-constant records, reaching perhaps 80 per cent difference between readings at times of maximum and minimum sunspot activity. The instrument promises to be of unusual value. Perhaps in this way will come the solution of a problem formulated years ago on finding the remarkable solar records in trees around the Baltic Sea.

TERRESTRIAL REACTION

Radiation and terrestrial temperatures—H. H. Clayton (1917 to 1926), while in the Argentine Republic, began using daily reports of the solar constant wired from Calama, Chile, in prediction of weather conditions for the succeeding 10 days over northern Argentina. This work he is continuing over parts of the United States in collaboration with C. G. Abbot, of the Smithsonian Astrophysical Observatory, under whose direction the solar-constant measures are made. Such prediction is based on direct effects in temperature observed in the two weeks or so following changes in the solar constant. Though still not accepted as conclusive by some (Marvin, 1925, etc.), the abundant tests already made seem to the writer to indicate a positive link in the chain of solar influence and terrestrial reaction. The full set of reactions as they spread over the earth is doubtless incredibly complex, and this appears to indicate something of the way the larger effects begin.

Radiation and drought—Dr. F. E. Clements (1921), who is working on the relation of drought to sunspot numbers, found from the rainfall records that when the relative numbers exceeded 80, a drought period of two or more years followed in the western United States.

Electrostatic reactions—The electrostatic charge in the atmosphere, earth-currents, and other electric conditions show response to solar activity. Dr. L. A. Bauer, of the Department of Terrestrial Magnetism of the Carnegie Institution, has done extensive correlation work (1923) and considers that terrestrial magnetic conditions vary with "agitated" solar conditions perhaps, rather than merely with extreme solar departures from the normal. Dr. Fernando Sanford, at Palo Alto, California, is making extensive records of atmospheric electricity and earth-currents and finds solar influence in a marked degree.

Glacial varves—Baron Gerard de Geer, of Sweden (1910, etc., 1926, 1927), has invented a method of measuring time by the annual clay layers, or varves, deposited under water during the retreat of the glaciers on the Scandinavian Peninsula and elsewhere. The process is given a firm scientific basis by a system of cross-identification of layers in different localities, similar to the cross-identification of tree-rings used in the present work. By this means he is able to enumerate several series of years, totaling some 18,000 since the glacial period. Measurements are made of the thickness of the layers, and thus evidence is found of temperature variations over long periods. The absolute date of these clay layers is known only within several hundred years. Dr. E. Antevs has applied the process in the valleys of the Connecticut and Hudson Rivers and at other points, finding some 4,000 years in the retreat of the glacial ice up the Connecticut Valley. These long sequences of annual layers displaying a temperature effect will be of greatest value in studying past climates.

Antevs's big-tree tests—Dr. Antevs (1925[3]) has made certain trials of the sequoias with reference to their use in studying past climates and reached an indecisive conclusion. But this result was anticipated from his selection of material and method of procedure. He divided Huntington's trees into basin and ridge trees, standardized them, and averaged these two classes separately without correcting the dating, and then compared the two curves obtained. These curves agreed for something like the last thousand years and before that disagreed. The difficulty lies in Huntington's incorrect dates (and possibly climatic change affecting the two groups differently). Basin trees grow rapidly and can be counted easily and so contain few errors, while the ridge trees are slow-growing and contain most of the errors. Hence, in them the average error would be of the order of twice the average error found in his dating, which was ±35 years in the last 1900. In view of these details, given in previous publications (Douglass, 1919, 1922), it should hardly have been expected that undated basin and ridge curves would show satisfactory agreement. On the other hand, it should be remembered that carefully dated basin and ridge sequoias show perfect cross-identification and only differ in the larger and more complacent growth of the former due to moist soil, as described in publications referred to.

Ocean rotation effects—One indirect effect of solar causes has been studied by Dr. C. F. Brooks (1926), namely, the rotation of the Atlantic Ocean under the pushing effect of the normal winds in different latitudes. The ocean is a vast storehouse of heat, whose variations are thus borne to different shores. The circuit takes some 2 years, and thus could originate short cycles of that order of length. Similar motion exists in the Pacific Ocean with probably an increased time of circuit.

Closely associated with the study of this ocean movement is the work of McEwen (1918, etc.) and Helland-Hanson and Nanson (1920) and others.

Solar cycle and terrestrial seasons—If a solar cycle of 10.5 months should exert a precipitation effect on the earth, it would alter the distribution of rainfall in different seasons, say in the temperate zone, and produce a 7-year cycle. We shall see that a cycle of this length plays a part in Arizona tree-growth, but it seems more likely produced by corresponding changes in solar activity and not as suggested above. If this short solar cycle were double the length given, or 21 months, and if its effect did not interfere with the seasons but increased tree-growth in each year of its occurrence, then we would find rings alternately large and small, as has been extensively observed. This is referred to in Volume I, page 106. Extended search has been made for a 2-year period by taking successive annual differences in growth

and reversing alternate signs, and plotting. Such curves have shown extensive 14-year cycles and half-sunspot cycles. However, on testing rainfall records for such period, the weight of evidence favors a broken or variable cycle of some 28 months (Douglass, 1915; Clough, 1924).

CYCLES IN TREE-GROWTH

CYCLE RELIABILITY

Definitions—The value of a record of the past is its service for the future, and prediction becomes possible as repetition is recognized. Repetition may come at irregular intervals, in which case it may be wholly accidental; or it may come at nearly equal intervals, in which case it constitutes a cycle; or it may come at exactly equal intervals, in which case it can be called a true period.

Short variations—In studying variations of weather and trees, the first characteristic observed is the great number of short variations. These are usually interpreted as accidental and without significance, for if any large number of annual values be drawn by lot and plotted, we shall find in the curve a maximum number of 2-year periods, a lesser number of 3-year periods, and so on in decreasing rate, all of which, of course, are accidental. So the weather at any one locality is full of small variations which it is useless to work on at the start. Such variations remind one of waves on water. We can picture a combination of land outline and winds which would produce an exceedingly complex wave system, but we could probably determine the origin of each. We do not get the same bird's-eye view in the distribution of weather and we have to class small variations as accidental in the sense that they are far too complex to disclose their origins at present. But while these variations are now of no value in weather prediction, their existence does not prevent the existence of certain short-period variations buried in them which are not accidental and whose origins are worth tracing.

Long variations—Accidental and illusive periods decrease in probability as the length of the period under test increases. Many accidental 2-year and 3-year periods have been found, and even one 11-year period in numbers drawn by lot, but 20-year periods or over have proved extremely rare in accidental sequences. Therefore, in the analyses which follow, periods under 10 years have been given little weight unless extraordinarily prominent, and as the length of period advanced from 10 to 20 years and beyond, more and more reliability has been credited to any evidence of periodic variation.

Criterion of reliability—A criterion for judging the reliability of cycles has been suggested which for simple reasons has not yet received extensive use. It is applied by taking all the values in a curve con-

taining the cycle, and twice drawing them out by lot; thus producing three curves, of which one is genuine and two spurious. If the genuine one can be distinguished from the others by the cycles alone, without other marks of identity, then the cycles are there. We can hardly yet make application of this to rainfall or tree-growth curves, because we do not know (or are just learning) what cycles ought to be there. On this account a half dozen criterion tests have resolved themselves largely into solving the question of the existence of cycles over 20 years, for that was the only known mark of identity. That in turn depended vitally on the length of the curve under test, for a cycle does not carry conviction unless it is repeated five or ten times in the record. So the trials on short curves of 50 or 75 years were not successful, while those on curves of 200 years were. It is probable that there will be extended use for this criterion, but in the absence of better knowledge of the cycles to be expected it has not been thoroughly tried and another method of judging reliability has been applied, namely, identifying similar cycles in many trees and over wide areas.

Cycle identification in small areas—In the early use of the cyclograph it became a matter of interest to know whether cross-identification could be done by cycles. To test this, an early general curve of the Flagstaff region was prepared as a standard. An assistant selected 125-year portions of other Flagstaff trees without letting me know to what tree or to what part of the 500 years they belonged. By cycles alone each unknown was compared with the standard 500-year curve. In the first trial of 10 unknowns, 7 were dated correctly, and in the next trial of 10, 8 were dated correctly. In other words, the cycles in any given tree in the region specified bear 75 per cent resemblance to a good average cyclogram of that region. Dating by size of individual rings is considered to have a reliability of 95 per cent or more. This decreased reliance in cycles is due in part to over-importance given in those tests to short-period cycles, before their unreliability was recognized.

Cycle identification at 200 miles—Two groups of 8 or 10 trees each, one from 40 miles north of Aztec, New Mexico (BMH), and the other from 18 miles east (AE), were compared with the Flagstaff records. The resemblance in the cycles is extremely close. Periods of 14, 17, and 21 years appear in all three groups in practically identical form. In this comparison cross-identification by cycles was carried over 225 miles of country (see Fig. 19 and Plate 9, page 132).

Cycle identification between Arizona and California—A still more difficult test was made between the Flagstaff area and the big-tree area. A selection of California trees was made in the following manner: The last 500 years of each of 34 trees were plotted and the resemblance of the cycles to Arizona and New Mexico cycles was reviewed and

each tree marked in some way to represent its resemblance. The best four (D–4, 16, 20, and 21) were then taken by themselves, having a regard both to this resemblance and to their wide distribution in California, and the average record of the 4 trees plotted for 2,000 years. These plots were slightly smoothed and duplicated so that each one overlapped its neighbor half-way, and nearly every part of each tree's record appeared twice. In exactly the same manner two other complete sequoia records were prepared; one was an average of D–3, 12, 20, and 23, preferred for showing the sunspot cycle, and the second was the "best selected" sequoias, with good consistent records. All these were prepared by an assistant and marked by him with a reference letter, so that I had no idea of the date or identity of any curve. The assistant then selected 250 years of Flagstaff tree-records whose exact dating was also unknown to me. Comparison was made by cycles between the Flagstaff record and the unknown sequoia records. After they were completed, all dates of resemblance were looked up, and it proved that instead of the six possible correct coincidences, there were a dozen apparent agreements, of which six, or 50 per cent, were correct and the other six scattering. Thus it appeared that in group averages there is a 50 per cent resemblance between the cycles in tree-growth in Arizona and those in tree-growth in California, and that a fair assurance in cross-dating between these two regions can be reached, if one uses, as in this method, enough data from which to obtain a convergence of results.

Advantages of the cyclograph—This instrument, which converts mathematical integration into a photometric process, has been used almost exclusively in the analyses about to be described. Its extraordinary advantage is its rapidity of analysis and its flexibility in showing the analysis of every part of the curve at the same time in the cyclogram or differential pattern, and also in its independence of fixed periods, for it shows many periods at once, whether fixed, variable, or broken.

Disadvantages of the cyclograph—The chief disadvantage is that in its present form one can not assign quantitative amplitudes. This could be done by passing the photographic negative of the cyclogram under a recording photometer, of which there are several types sufficiently accurate. The amplitudes could be derived easily from the galvanometer curve.

PERIODOCRITE

Professor C. F. Marvin, chief of the United States Weather Bureau, has suggested (1921) the use of a process which he names the periodocrite. It simply solves the question: does the application of a given cycle reduce the probable error? If so, the use of the cycle is justified.

ZONE CENTERS AND THEIR MEAN CURVES

The material collected over western areas has opened such a field for immediate development that the contents of this chapter can only be regarded as a transition rather than a conclusion. Such progress and results as have appeared to date will be given, but they must be taken as subject to revision at a later time.

Cross-identification—Introductory to the comparison of smoothed curves, it should be recalled that cross-identification by individual rings is the exact and reliable method of comparing curves over large or small areas. In the western States it is found to grow easier and more reliable as the climatic stress of the arid regions is approached, that is to say, such dating is highly satisfactory within the Arizona region, which extends to the Rio Grande on the east and the coast-line on the west. It is fairly satisfactory between Arizona and Central California, as also from Arizona to the central Rockies, but the northern States, with a very different tree-record, do not cross-date with Arizona. An electrical instrument is now under construction which it is hoped will reduce this cross-dating by individual rings to mechanical quantitative measurement. When that is accomplished it will perhaps be possible to express similarity between groups by a single coefficient.

Comparison of smoothed curves—The crests of these curves give the phase or epoch of maximum of the various cycles which may not be the same in different regions. Two results appear in this curve comparison, namely, first, a real separation into the three zones, and second, a latitude effect in which there is much more similarity east and west between the zones in their southerly or drier parts, than in the northerly moist latitudes.

Flagstaff area mean curve—In consequence of the southern similarity just mentioned, the Arizona area could be regarded as exceeding the others in size, for Pine Valley and Charleston Mountains show similarity on the west, and Basin Mountain, Aztec East, and Santa Fe repeat Arizona features on the east. However, the Catalina and Santa Rita Mountain groups near Tucson show marked differences. The Flagstaff area presents an excellent central homogeneous collection of curves from the Grand Canyon to the Rim and Cibecue, a distance of 175 miles (GC, FV, SH, NE, FL, FLU, RL, and J). These curves have been combined together graphically and the mean result, 1702 to 1920, is shown in figure 18, upper curve, page 128. This curve is important, because it is probably a better rainfall curve than those of the other zones. We note that shorter periods are largely smoothed out, except parts of a 7-year cycle. A period of 21 years (with lesser 14-year effects) strongly dominates, thus agreeing with a result reached in 1908 and referred to in the previous volume (p. 104). The sunspot cycle with its half and double appear in the early parts of the curve,

as also 8.5 and 17 year cycles. Further discussion will be found below under Solar Records in Tree-Growth, page 125.

Pike's Peak area mean curve—The groups in the Rocky Mountain zone cover a smaller area than those in the other zones. Thus the area represented by the mean curve is limited to the east slopes of Pike's Peak in the vicinity of the Cog Railroad. The homogeneous

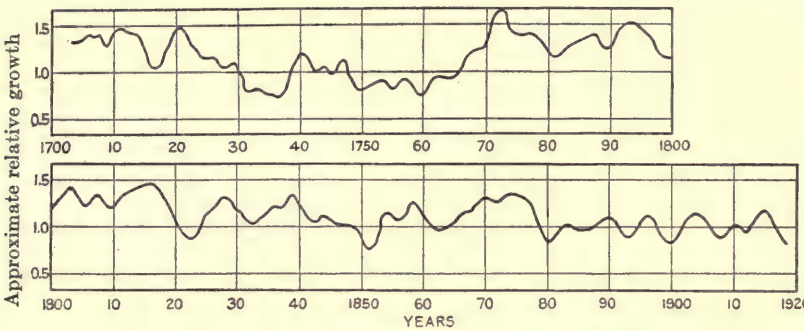


Fig. 13—Pike's Peak area mean curve, PPM; average of six groups, standardized and smoothed

collection of groups includes six, PPB, HNT, LNT, C, ST, and BDF. The Laramie group and those from Santa Fe and the Aztec region are similar, but not quite enough like the central collection to be included. The mean curve of the six named is shown in figure 13. It appears to show strongly a 5, 10, 20 year cycle and a triple sunspot cycle divided into halves and quarters (that is, an 8, 17, 34 year cycle).

Sierra Nevada mean curve—The distribution of groups in this zone is better than in the other zones. From The Dalles in northern

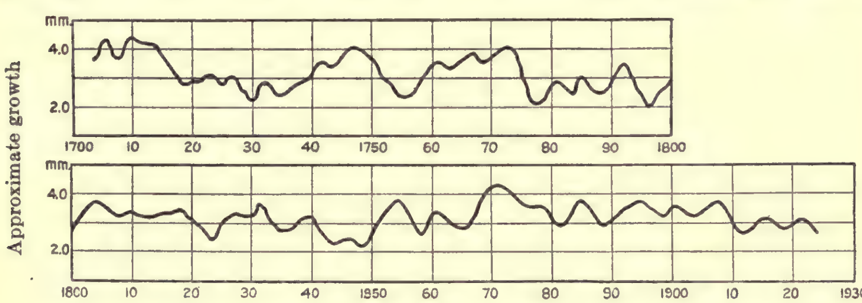


Fig. 14—Sierra Nevada area mean curve, SNM; average of four groups, standardized and smoothed

Oregon to Pine Valley near San Diego the nine locations are fairly well spaced. There is pronounced similarity in the smoothed curves in all of these except Klamath Falls and Pine Valley, but the best agreement occurs between those in the Sierra Nevada Mountains from Calaveras to Mount Wilson and the mean curve is the average of these, namely, CVP, BC, EP, and W groups. It is given in figure 14.

It will be noted that this inner group does not include the trees from San Bernardino Mountain, which show a remarkable double sunspot cycle. These were not included because they seemed to represent an extreme condition of some sort which should be studied by itself. A preliminary analysis of the Sierra Nevada mean curve shows a 5, 10, 20 year cycle, very strong in early half (1700–1800), a 5.8, 11.8, 22.8 year cycle, strong in the late half (after 1800), and a 7 ±, 14-year cycle growing strong in the late half.

METEOROLOGICAL AREAS: THE PROBLEM OF COMBINATION

Use of trees in outlining meteorological areas—Very few weather records reach 100 years in length, and they are apt to be at widely scattered places, subject to different conditions, such that the records can not be combined advantageously, but a forest gives a vast number of long records in some definite region. With proper care we do not need to mix records of different types. No doubt we have exaggerations, and in young trees we have a smoothing-down of variations. In terms of thermometer and measuring-rule, our values are not of the highest precision, but as seen from the viewpoint of actual growing vegetation the tree record is hard to surpass.

Disadvantages—While we have as yet no substitute for the length of record given by the trees, the chief difficulty is that the reaction of trees to certain weather elements that physical conditions make it easy for us to measure (temperature, precipitation, etc.) is not everywhere proportionate to these causes and under certain conditions may be fundamentally changed, as, for example, in the reaction to moisture in wet climates. The differences between the zones as shown below is perhaps in part an illustration of this. That investigation is as yet unfinished.

Problem of combination—Meteorological reports are collected in various districts which are political subdivisions, and are not outlined by weather conditions. When the student begins to combine areas in order to get general averages, he is confronted at once by the problem of combination, for before combining he has to find out what areas it is safe to combine without losing valuable material. The error of too large combination kept meteorologists from admitting solar effects in weather for a score of years.

Tree-record combinations—In work with the western groups the general experience has been that trees in the same forest are very much alike and may be combined without loss, if care is taken to use trees exposed to similar conditions of soil-moisture. Thus the groups were formed. In combining groups the guides have been: (1) geographical outlines of zones, (2) obvious similarity in smoothed curves which probably is equivalent to phase similarity in cycles, and (3)

obvious similarity in cycle-length. The relations between phase and zone have been described above in connection with smoothed curves. The relations between cycle-length and zone are now under consideration.

Effect of combination on cycles—In a previous chapter the cycle analysis of each group was given, some 42 groups. Here we have a large number of widely scattered small units. The dominance of certain cycles in these zones seems very significant. When we combine the curves and use the mean curve for a homogeneous area, the cycles in this general curve are reduced in number, giving a few powerful ones and only traces of others.

Present importance of small units—It is felt that the group is still the important unit for analysis, and though more general combinations are illuminating and helpful, the fundamental information is in the group.

CYCLES IN WESTERN ZONES

Arcigram—In a periodogram the ordinates give the amplitudes of the various periods in a given curve. In the summaries below the ordinates give the number of occurrences of each cycle-length over a given area, and for the present the word "arcigram" is used to refer to this kind of a diagram. The distribution of cycle-lengths in the three western zones is shown in figure 15.

Derivation of ordinates—The number of groups in the three zones is nearly the same: Arizona, 14; Rockies, 15; Coast, 13. In the first plotting of figure 15, the ordinates consisted of the number of occurrences of cycles in each half unit of period; for example, those between 12.0 and 12.4 inclusive, and those within 12.5 and 12.9. But in the original analyses three weights had been assigned, and in the curves in figure 15 each occurrence is counted one, two, or three times as it was assigned weight. This inclusion of weights made no essential change in the curves.

Western area cycles—The cycle occurrences in the three zones were counted and plotted separately, and the important characteristic appeared that the cycles are much the same in each, with somewhat different emphasis. This similarity, as shown in the figure, is evidence in favor of the approximate values here given, which appear to be very nearly simple fractions of 34 or 35 years, as can be seen in the following list:

6.8	$\frac{1}{5}$	17.2	$\frac{1}{2}$
7.6 (rare)	$\frac{3}{14}$ or $\frac{2}{9}$	20.5 ± 1	$\frac{4}{7}$ or $\frac{3}{5}$
8.6	$\frac{1}{4}$	22.5 to 24.0	$\frac{2}{3}$
10.2	$\frac{2}{7}$	25 + (rare)	$\frac{5}{7}$
11.2 to 11.7	$\frac{1}{3}$	28 ± 1	$\frac{4}{5}$
14.2	$\frac{2}{5}$	$31 \pm$ (rare)	$\frac{6}{7}$
		$35 \pm$	1

This relationship of western cycles only appeared in recent work and is still provisional. It may be real, but, on the other hand, there may be some preferential selection by the analyzing instrument or the observer, in spite of great effort to get rid of such errors. It should be added that the cycle given as 20.5±1, really covers the interval from 19 to 21, and could have interpretations at 19, 20, or 21 years. The brief study, given later, of solar records in the long Flagstaff tree-records, throws a little more light on this.*

FIG. 15—Cycles in western zones

Arizona zone—The Arizona zone is distinguished by the absence of 8, 10, 11, and 17 year cycles and the great dominance of 14 and 20 years. Its double sunspot cycle averages a little over 23 years.

Rocky Mountain zone—Cycles of 10, 11, and 14 years are largely lacking. The 8+ and 17 year cycles have more prominence here than in the other zones, but the 20 and 23 year cycles are the strongest in the zone.

*Recent independent tests sustain these results.

Coast zone—Cycles 17 and 20 years are largely lacking. The 10 and 11 year cycles are stronger here than in the other zones, but the 23-year cycle is the strongest in this zone.

Zone summary—The characteristics of the three zones are brought out in the following list:

Zone	Prominent	Deficient
Arizona	14 20 years	10 11 17 years
Rockies	8 17 20 23	10 11 14
Coast	10 11 14 23	17 20

Sequoia cycles—The above summary deals almost entirely with the yellow pine; for comparison the cycle analyses of some 32 sequoias, from 1400 on, have been combined into one arcigram which agrees

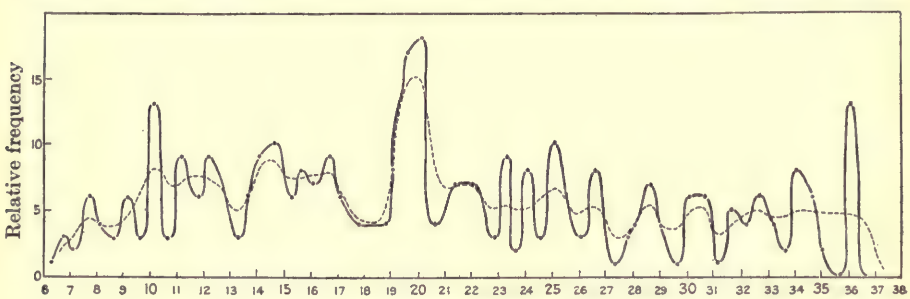


FIG. 16—Sequoia cycles

with the pines in the coast zone in giving prominence to cycles of 10, 11, and 14 years, but differs from them in having a very prominent 20-year cycle with lowered emphasis on the 23-year cycle. This includes the entire list of sequoias in the General Grant Park region without selection of any kind, and indicates more resemblance to the Arizona reaction than appears in the pines of the same area.

SOLAR RECORDS IN TREE-GROWTH

Historical confirmation—From the start the sunspot cycle was sought in the Arizona pines, and during large portions of their growth it seemed perfectly evident, but for scores of years near 1700 it failed entirely; in 1914 the writer very nearly gave up the idea that the trees show it. In 1919 (Volume I, p. 102) the cycle record was given with the statement that from 1660 to 1720 the sunspot curve "flattens out in a striking manner," and again, "the sequoias show strikingly the flattening of the curve from 1670 or 1680 to 1727," and again, "it seems likely that the sunspot cycle has been operating since 1400 A. D.,

with some possible interference for a considerable interval about the end of the seventeenth century." Early in 1922 a letter was received from Professor E. W. Maunder, of England, calling attention to the prolonged dearth of sunspots between 1645 and 1715, and saying that if there were a connection between solar activity and the weather and tree-growth, this extended minimum should show in the weather and in the trees. On receipt of the letter, this period was immediately recognized as the interval referred to in which there was entire failure in attempting to trace effects of the well-known solar cycle. The sequoia record for the last 500 years, as summarized in figure 33, page 103, of the previous volume, confirms minutely the result. So also do the Vermont hemlocks and other tree-records.

Dearth cycles—In 1922 or before it was noticed that when the 11-year cycle disappeared from the trees near 1700, two other cycles, one of 10 or 20 years and the other of 7 or its smaller multiples, became prominent in its place in the Arizona pines (see Plate 9 and Fig. 19). Soon after, it was noticed that the Vermont hemlocks and the sequoias of California show similar change at that time. And then it was observed that these three cycles appear generally in the western trees; they are, first, the known sunspot cycle of about 11½ and its double of 23 years; second, 10 or 20 years; and, third, 7, 14, 21, or 28 years. These three cycles, with others mentioned below, have been confirmed in the present study of the 42 western groups. There is some reason to think that all of these cycles come from the sun, for at different times the sunspot cycle itself has changed to one or the other of them. For example, from 1748 to 1788 there were four complete cycles of close to 10 years each; and from 1788 to 1837, 49 years, there were three complete cycles of about 14 years each and one of 7. It seems at least likely that these other two cycles, found in western trees with extraordinary persistence, are also of solar origin.

Wet and dry climatic effects—In this study of cycles in the western yellow pine it was found that in this dry region, where trees are specially sensitive to rainfall, they show, besides other cycles, a double-crested 11-year variation, just as the rainfall itself does, but in the moist coastal regions this solar cycle has more often a single crest like that of the sunspot numbers. This agrees with the result of 10 years ago, in which the wet-climate Scotch pines of North Europe, especially near the Baltic Sea, showed a direct single-crested cycle having a remarkable resemblance to the curve of sunspot numbers (Volume I, p. 77). Their growth gave the solar changes with an accuracy exceeding that of any trees of the southwestern area. (See S–14 in Plate 9.) This remarkable solar record is a wet-climate phenomenon, but it is not yet clear just what causes its accuracy. It seems probable that these trees follow the sunspot cycle more

Spruce, S-14, from South Sweden, showing sunspot cycle; wet climate reaction. Dots give dates of sunspot maxima beginning with 1830

closely than do the weather elements in which they live, and it is perhaps safe to repeat the suggestion made by the writer in 1922 that there may be some more direct line of cause and effect from the sun to these trees than we have taken into account, such, for example, as radiation (possibly of short wave-length), that is especially favorable to trées growing generally under cloudy skies. In tree-groups along the Atlantic coast of this continent, the 11-year cycle is also prominent, but it has a phase displacement of 2 or 3 years.

SOLAR CYCLES

Eleven-year cycle in long Flagstaff record—Combining the long Flagstaff century curve beginning in 1285 with the Flagstaff mean

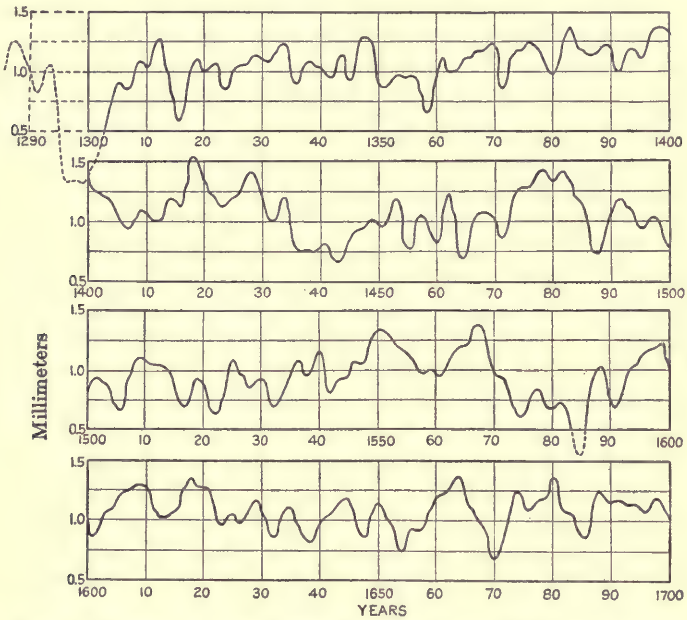


Fig. 17—Flagstaff century curve, FLC, A.D. 1285–1700; standardized and smoothed

area curve from 1700 on, one has full 625 years of sensitive tree-growth (see Figs. 17 and 18). To this a superficial graphic analysis has been applied with a number of interesting provisional results. The first test deals with the extended half-sunspot cycle in the early Flagstaff curve, found in 1908 and shown on page 102 of the previous volume. The first hundred years of our present curve is made up of several radials of one tree which had suffered a considerable injury in 1295. It begins to show the cycle with certainty about 1320. The cycle continues without interruption till 9 other trees join it between 1385 and 1419, during which time it is discordant, probably in part from poor merging process in adding the new trees. Then it continues without discord till 1541, 1550, and 1566–67. After that it is in

accord again till 1617, and from there on it decreases its accuracy, and the variations typical up to that point disappear from the curve. The curve from 1700 on shows much less of the sunspot variations, but in the Grand Canyon group, one of its components, and others also, the half cycle shows well from 1850 to the time of collecting and with almost the early regularity. Brief calculations show that the

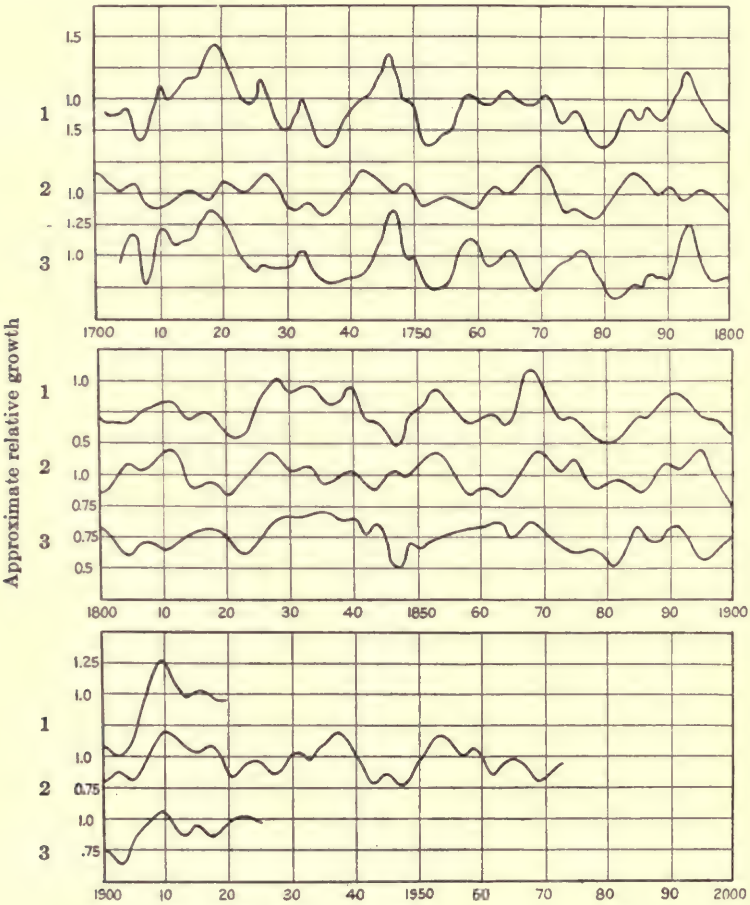


FIG. 18—(1) Flagstaff area mean curve, FAM; average of eight groups, standardized and smoothed; (2) synthetic curve; (3) residuals

long variation in the earlier curve agrees exactly in phase with the recent years, and so we find through practically 600 years a mean value of the sunspot cycle of 11.30 ± 0.02 years. From the correlation diagram already referred to on page 104 of Volume I, we see that the most direct relation between the double-crested growth-curve of the above stated length and the single-crested sunspot curve is that a growth maximum occurs at the time of a sunspot minimum. On

plotting in the early times of sunspot maxima and minima, according to Wolfer, we find that the telescope was invented and spots observed just in time to show that it has always been the same maximum of the double-crested tree-cycle that came at sunspot minimum. This in itself is an interesting fact, for it intimates that the 11-year cycle can be called a well-defined period which the sunspots do not always follow exactly. Apparently, the 11.30-year period and the sunspot cycle are two different things.

Seven years and multiples—There is further information in the tree-records which perhaps adds light but does not fully solve the solar puzzle. The Flagstaff area mean curve in figure 18 has some large variations which are roughly solved without difficulty. A 21-year cycle is very prominent and a 14-year and a 7-year cycle easily evident. These values seem to be very close to 7.0 and its multiples. The time of maximum of the shorter periods is about 1910 and for the 21-year period possibly 4 years later. This, however, is not a rigorous solution. The amplitudes (from the mean value) increase from 5 or 10 per cent in the 7-year to double that in the 14-year and triple in the 21-year periods. This group of multiples of 7.0 becomes evident about 1663 with a large maximum of the 21-year type. It rather fails in the 1680's, but after 1700 comes in regularly. Its beginning is thus connected with the great dearth of sunspots described by Maunder (1922). A single maximum of this apparent type occurred in 1479.

Nine-year-plus cycle—A very crude graphic synthesis of these periods has been made (and extended to 1980) whose resemblance to the original curve is fair. This is shown in the central curve in figure 18. So a set of residuals between it and the original was plotted and two interesting features appeared, as shown in the third curve of Figure 18. A set of crests came in 1747, 1758, 1766, 1777, 1786, and 1794, all of which except the last came close to the sunspot minima during that unique interval when the sunspot cycle averaged about 9.3 years in length. (The minima were 1755, 1766, 1776, 1784, 1797.) The length derived from these crests is 9.4 years, which thus gives us a terrestrial cycle related immediately to a definite solar cycle. It is possible that the fairly common climatic cycle of 19 years is the double of this solar cycle. From 1800 to 1880 the agreement between the natural and synthetic curves is good, except for the extreme minimum growth in 1847 and 1880, 33 years apart, and from 1880 to 1905 the 7-year cycle is practically absent, reappearing again subsequently.

Historical changes—In a general way it is safe to say that the sunspot cycle and its double and triple values are very common. The double value has persisted in Arizona for 600 years with interruption from 1630 to 1850 or thereabout, and in some North European localities it shows for the last century and a half covered by our tree groups.

The triple period, essentially Brückner's cycle, has operated in Arizona for the last 200 years and in Norway for 400 at least. Western zone cycles are largely its simple fractions. A hundred-year cycle is prominent throughout the 3,000 years of sequoia record, and a cycle of about 150 years shows in the 600 years of yellow pine. It seems fairly probable that the 11-year cycle can be judged by the variations in its double value, which in some cases is more easily traced through long periods. A very incomplete review of the sequoia record suggests that from 1300 B. C. to well after 1100 B. C., the 11-year cycle was strongly developed. Near 300 B. C. it was again apparent, though not very conspicuous. During the first two centuries of our era it was again highly dominant. It reappeared from 375 to 475 and from 600 to 650 and was operating during much of the ninth century, though mixed with other cycles. Then it appears only occasionally until after 1300, when it again becomes fairly continuous, except for the changes in the seventeenth century (1633 to 1712) above noted. This is a provisional report and will, without doubt, receive changes when the sequoia records are minutely examined for the purpose.

Climatic patterns—From this study of the geographical and historical distribution of climatic cycles it is inferred that they are climatic patterns made up of interferences between a number of simple fractions of a few fundamentals, traceable to solar influence. This form of interference seems to produce pseudo-cycles which vary with the phase relationship of the fundamentals and whose resulting temporary character has always been a stumbling-block in the way of investigation.

CYCLOGRAMS

An analytical review of some of the cycles mentioned in this chapter is given in Plate 9. To one who understands the extent of information in the cyclogram, and, if I may add, the spirit of this information, that is, its frankness in showing its own accuracy or error, these figures visualize the facts in a most compact and convenient way.

Cycle identity across 200 miles—The first three cyclograms, taken in immediate succession on the same plate, show an analysis at a period of 18.1 years (represented by the thread) of the Flagstaff curve and the two points near Aztec in northwest New Mexico, from 1700 to about 1910. The most conspicuous alignment is the 21-year cycle, but 17- and 14-year cycles also usually show. The similarity in general pattern is apparent at once. This is evidence of the reality of the cycles and of their climatic significance (page 118).

Dearth cycles at A. D. 1700—The Vermont hemlocks give an analysis shown in cyclogram 4. Here the Brückner cycle dominates from

1650 for more than 100 years, accompanied by a 28-year cycle, of which traces are found to continue even in the late half (1775 to 1900), in which the sunspot cycle and its double prevail. The latter condition extends from about 1750 to the present time. In the early half also a 20-year cycle is faintly shown by a distinct alignment, as marked in the explanation diagram. So in this record also we find the 11-year cycle replaced by 20- and 28-year cycles during the dearth of sunspots near 1700 and for a brief time after, that is, to about 1750.

Cyclogram No. 5 gives an analysis of the sequoia record in four trees, D–3, 12, 20, 23, which were selected for their excellence in showing the solar cycle. The interval covered is the 400 years from 1450 to 1850 at a set period of 23 years, represented by the thread. The change from the double sunspot cycle to the 10, 20-year cycle took place near 1630. At about 1700 all three cycles (10, 20, 23, and 28) begin to show. In the last half century or so, the 20-year cycle dominates, which agrees with the "arcigram" of the sequoias mentioned a few pages above. The dearth cycles (20 and 28) were forming by 1550 more or less, and they are the ones which prevail during the absence of sunspots near 1700.

The Flagstaff evidence of dearth cycles is shown in cyclogram 6. Here it is easy to trace the double sunspot cycle from 1400 to its end near the center at 1650. The 14, 28-year cycle enters at about 1550, but after 1700 it is practically lost, due to smoothing and the great dominance of the 21-year variation, which continues to the end. The 35-year variant begins not far from 1700. This cyclogram was taken in 1921 from the original Flagstaff group, smoothed by 5-year overlapping means; all the others shown are from original unsmoothed plots or from Hanned curves.

Flagstaff long record—Cyclograms 6, 7, and 8 show the analysis of the long Flagstaff record (500 years used here) at three different settings for cycle-length, 22.1, 14.0, and 7.0 years. The first, as just described, shows the main features of the sunspot cycle to 1650 and the 21-year cycle since 1700. The second gives more detail. The 14-year cycle enters near 1500 and continues to the end. The 11-year period, often double, may be traced from 1400 to well after 1600. A 9- to 10-year cycle is evident from about 1650 to 1775 or so. Thus the "extra" cycles (10 and 14) are clearly found connected with the dearth of sunspots about 1700.

The Flagstaff analysis at 7.0 years is given in cyclogram 8, but the numerous short cycles shown are not so important and sure as the longer ones already described.

Arizona drought cycles—There is no doubt that a demonstration of the periodic action of droughts would be of great value to the Southwest. Accordingly, in 1925 a "skeleton" plot of Arizona droughts,

shown in the trees, was made and analyzed. The major dry periods came at 1440, 1580, 1735, and 1880 to 1900, or an average of about 150 years apart. Also, the single tree which gives a record beginning at 1285 shows a great depression at 1295 to 1300, which conforms to this 150-year spacing. Thus the major droughts give a cycle which was long since (1914) noted as occurring in the Arizona record. Cyclograms 9 and 10 show analyses at 14.6 and 20.2 years as the best to

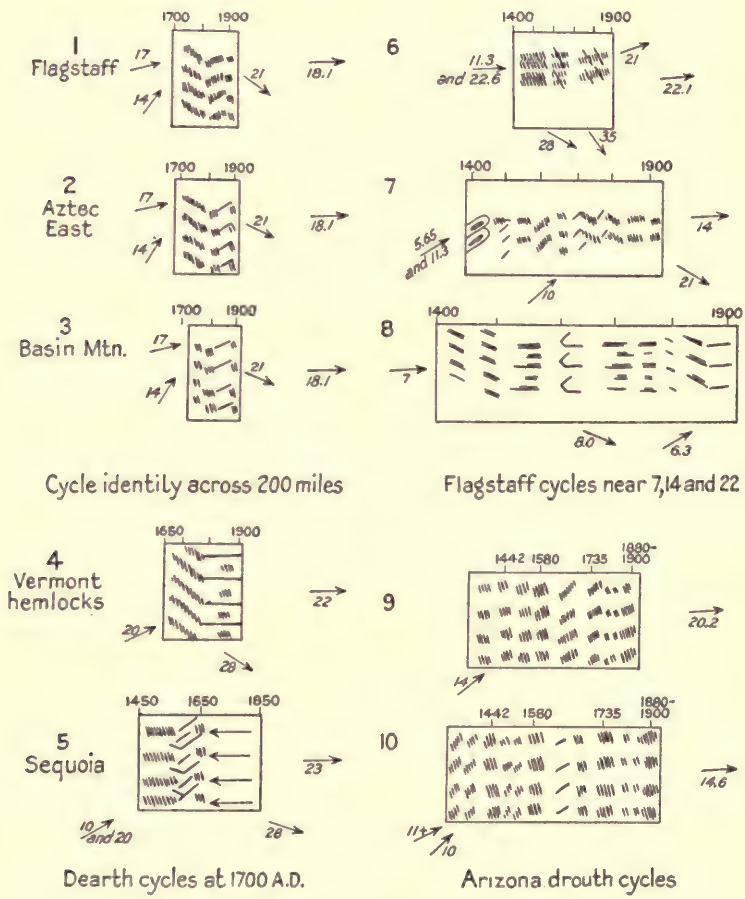


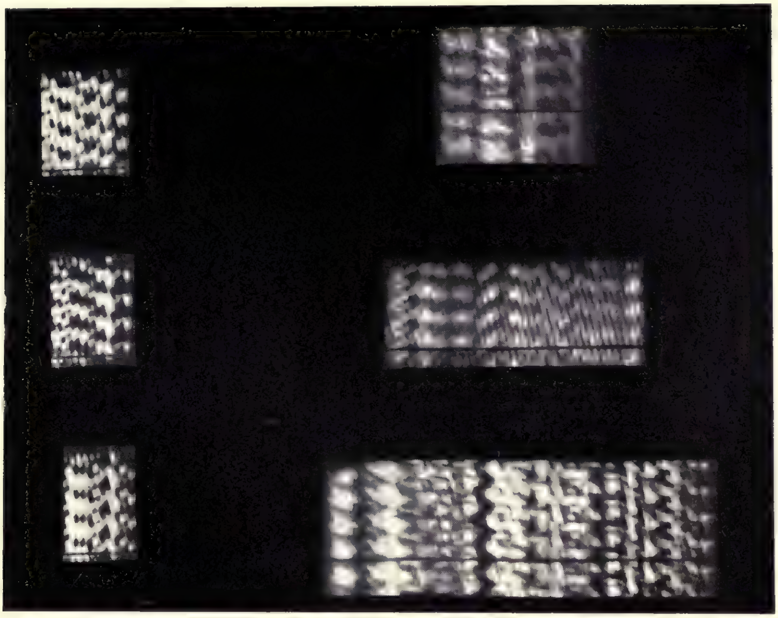
FIG. 19—Details of cyclogram patterns in Plate 9

cover this 575-year lapse of time. These cycles are near the 14.0 and 21.0 values and may be identical. It will be seen that there is a tendency to group the droughts at intervals of something under 50 years. This could be 42 years, the interval at which 14- and 21-year cycles have their major effect on each other. Probably the 150-year effect emphasizes whichever 21-year multiple is nearest, with some modification from the 14-year cycle.

1 6

2 7

3 8

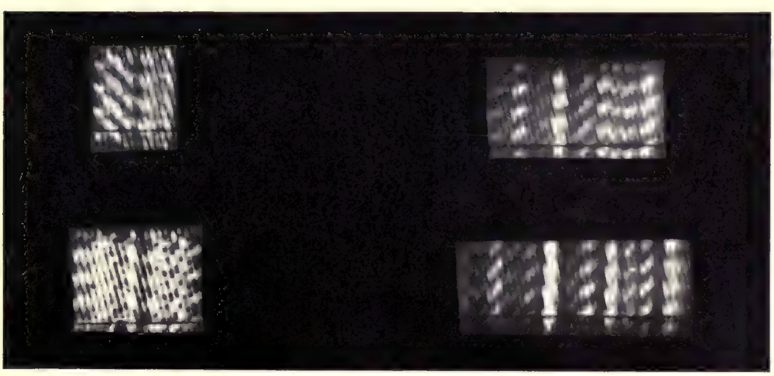


1, 2, 3—Identity across 200 miles

6, 7, 8—Analyses of Flagstaff pines

4 9

5 10



4, 5—Dearth cycles near 1700 A.D.

9, 10—Cycles in Arizona droughts

Cyclograms

Explanatory diagram on opposite page

CYCLES AND CLIMATE

Three major lines of interest have emerged in this study of cycles as it has developed in this chapter. The first was the distribution of cycles over western areas in approximate simple fractions of 35 years (or perhaps the triple sunspot value of 33.94 years); the second is the history of cycles in the long Flagstaff record and their agreement with solar changes, thus throwing light on solar history; the third now to be considered is the problem of prediction, which depends directly on the climatic significance of the cycles previously discussed. Their climatic character seems open to no reasonable doubt. Dating and prediction, the backward look and the forward look, both depend on a knowledge of the historic and geographical distribution of these cycles. In each it is better to test out a small locality first, such as the Flagstaff region, in order to avoid the complexities which arise over too large areas.

First caution: Interpretation differs with locality—The Arizona trees respond closely to a definite weather element, rainfall, the most important element in the prosperity of the country, but in the moist areas this direct response decreases and even disappears. Hence, the first caution in this process is that we must not assume relationships similar to those in Arizona in any given place until that place has been thoroughly investigated.

Second caution: Cycle changes not understood—The second caution is very important. Until we know the physical cause of cycles we can not say how long a mechanical repetition will last, for it may break down at any time. This is well illustrated in the solar changes shown in the long Flagstaff record. For hundreds of years the 11-year cycle was dominant, and then in the middle of the seventeenth century it faded out and gave place to others, and we do not yet know the reason. Until we know the reason we can not be sure it will not happen again in the near future. Fortunately, we have the long-lived sequoia for testing out secular changes. The best results from it at the present time were given in a historical summary above.

Variable star analogy—There are several variable stars which are dominated by different periods for irregular intervals of time. One of the best is SS Cygni, which has been observed carefully for more than 30 years. It is not visible to the naked eye, but by telescopic observation has been found to rise suddenly from the twelfth to the eighth magnitude at intervals of 50 or 60 days, more or less. Alternate maxima are often of different length, reminding us of alternate sunspot maxima. Then without warning the period changes. Dr. Leon Campbell, of Harvard College Observatory, has given me data and for years I have tried to find the rule which governs these changes.

Third caution: Cycle subdivisions—The splitting of cycles that may differ in different localities causes an uncertainty in place of

maximum or minimum. Consider, for example, a yearly curve of temperature, low in winter and high in summer. Impress upon this, as we have in Arizona, a summer rainy season which lowers the daily averages and produces a slight summer minimum. The maximum is split and driven each way, but owing to the lag in effects the higher maximum comes in June. If a cycle is split we need to know whether it is the maximum or minimum that changes. If only one changes we get a double-crested curve and if both maximum and minimum split we get a three-crested curve. In the 120 or 130 analyses of western groups, certain cycles, obviously the same in each case, were sometimes found single, sometimes double, and very rarely triple. Hence, it is evident that the comparison of dates of maxima and minima is a complicated process.

Fourth caution: Interference cycles—If some tree cycles arise, as is possible, from an interference between some external short cycle, say 10.5 months, and the annual seasons, then it is evident that the time of maxima would not necessarily be the same in different geographical locations, for the time of favorable season is different. Comparison between the northern and southern hemispheres would be needed to settle such cases, for similar conditions in the two hemispheres would reverse the cycle. A single curve from Tasmania suggests a split 35-year cycle, with major maximum about 1891 and minor maximum in 1908. In the early Arizona curve the maximum of the 35-year cycle was put about 1900, but in the recent study of western groups this 35-year cycle is usually split into two 17-year cycles whose maxima come in 1892 and 1909, thus agreeing with Tasmania.

Fifth caution: Cycle centers—In the western zones it was found that each zone had a homogeneous central area with scattering variations about it and that intermediate points, such as the Charleston Mountains, partook of the variations of each zone near it. It is not impossible that we shall find several more central homogeneous areas from which certain typical effects spread out. It is evident that in such conditions many intermediate places will have badly mixed conditions, so that prediction of any kind will become additionally difficult.

Flagstaff area synthetic curve—The mean curve covering the area from the Grand Canyon to the Rim shows very excellent similarity to the individual curves composing it, but many of the short periods have disappeared and multiples of 7.0 years are left prominent, 21 years being by far the strongest. Residuals between the synthetic curve and the real growth-curve show a 9.4-year cycle in the latter part of the eighteenth century. Crests are too high (in the natural curve) at 1793 and 1891 and the minima at 1847 and perhaps 1880

are too low to be accounted for by the synthetic curve. The 7-year cycle was almost absent from 1880 to 1905. Yet on the whole there is a good deal of similarity. The prolongation of the synthetic curve shows a small depression near 1927 and deeper ones at 1942 and 1947. The interval during the 1930's has high ordinates with an unimportant depression at 1933. It is possible that the 1947 depression may resemble the one of 1847 and be rather extreme. During the 1950's the curve is again high. High crests occur at 1937 and 1953. It is not expected that this is entirely right, but the details are given here in order to assist ultimately in finding the true variations.

SUMMARY

The foregoing book includes the following descriptive matter:

1. The technique of collection and preparation of material brought up to the latest development, with special studies of trees and rings.

2. New instruments constructed and used, namely, the tubular borer, the automatic plotter, the longitudinal plotter, and the White cyclograph (periodograph without the attachment for producing the periodogram); the cyclogram is here definitely used in place of the periodogram.

3. The collection of long tree-records including (*a*) sequoia groups from Calaveras and Springville, (*b*) coast redwood groups from Santa Cruz and Scotia, (*c*) a 640-year yellow pine, and (*d*) much archæological material for constructing a very long yellow-pine growth record.

4. The collection and measurement of 305 yellow-pine ring records in 42 groups, from 10 western mountain states, representing the area from the eastern slope of the Rockies to the Pacific coast and extending from the Mexican border to the latitude of the Columbia River. Practically all these trees were standardized individually before obtaining group averages.

The results obtained and described are as follows:

1. All the sequoia groves from Calaveras to Springville give the same climatic record and can be cross-identified throughout their records; the northern groves are more complacent in ring-type.

2. The coast redwoods, carefully selected and most carefully compared, could not be cross-identified and therefore are not used.

3. Ten-inch boring tests every 20 feet on a sequoia 265 feet long and 15 feet in diameter, which fell in 1901, gave almost perfect similarity throughout in the heartwood, but very considerable differences in the water-soaked sapwood. The problem of change in ring-size is opened. In living trees the change is probably very small and connected with conservation of moisture, sometimes possibly retroactive on the rings.

4. Topographic studies show that soil moisture is a strongly controlling factor in ring-type, both in sequoia and yellow pine. Soil-moisture gradient below the trees could be used as an indicator of ring characters.

5. Trees at higher altitudes and at higher latitudes (than about 32° N.) show more complacent rings.

6. Close grouping in the pines and sequoias produces objectionable alterations in rings only under extreme conditions and can be avoided with trifling care in selection of trees.

7. Deficient soil-depths and denudation of soil about trees produce intensely compressed outer rings in the pines of dry areas, and this character can be recognized in much prehistoric material.

8. Mean sensitivity is a good indicator of climatic correlation, but it is strongly affected by injuries to the tree.

9. Average ring-size, doubling, changing, and other characters of rings can be used as indicators in judging the surroundings, and especially the climates, of prehistoric and geologic times.

10. The Prescott correlation between rainfall and tree-growth is continued and a similar correlation is found between the Flagstaff trees and the winter rainfall recorded there, which, in turn, closely resembles California precipitation. A close correlation is also found between carefully selected (dry ground) sequoias and San Francisco rainfall.

11. By comparison of smoothed curves, three western centers appear; Pike's Peak, Flagstaff, and Sierra Nevada. The Pike's Peak area as worked out covers the eastern slope of the mountain; the Flagstaff area extends from the Grand Canyon to the Rim and Cibecue, 175 miles; the Sierra Nevada area extends from the Calaveras Grove and even farther north to Mount Wilson and farther south, 500 miles. In each of these the curves of growth are homogeneous, and at points between these major centers, such as Charleston Mountain or Aztec, mixed effects are found.

12. Dating comparisons of cycles in 200-year curves show 75 per cent resemblance in local curves of individual trees, and 50 per cent resemblance between Arizona pines and California sequoias, by large groups of trees. Practical identity of cycles in yellow-pine groups is found across 200 miles between Flagstaff and northwest New Mexico.

13. The cycles found in the yellow pines of the western zones emphasize the approximate simple fractions of 34 or 35 years, with 11 and 14 years dominating on the coast, 14 and 21 years in Arizona, and 10 and 11 (or 23) in the Rockies; the coast is deficient in the 20-year variations (the separation of 19, 20, and 21 is not yet fully determined in these zones); Arizona has less of the 11, 23 year cycles and the Rockies are short in the 14, 28 year cycles; they, however, show the 8.6- and 17.5-year cycles better than the other zones.

14. A sequoia arcigram (cycle summary over an area) shows a little more of the Arizona character in the sequoias than in the yellow pines of that region.

15. The long Flagstaff record, from 1300 to 1925, perhaps the best in the three zones for rainfall history, gives cycles which check with the known solar record. From them we get a solar period of 11.30 years lasting for 600 years, but with an interruption from 1630 to 1850; we get also a group of 7, 14, and 21 year cycles beginning near 1660 and well established after 1700. The 21-year cycle has dominated Arizona tree-growth for 200 years. A 9.4-year cycle shows in the late 1700's, when the sunspot cycle was of that length. The 7-year cycle was less active from 1880 to 1905 (in the Flagstaff area mean curve). Growth maxima occur at observed sunspot minima.

16. Wet and dry climate effects in trees in relation to the solar cycle are confirmed.

17. Provisional results indicate that the 11-year cycle appears in the long sequoia records at 1300 to 1100 B. C., 300 B. C., A. D. 35 to 240; 375 to 475; 600 to 650; 800 to 900 and 1250 onward, with the interruption following 1700.

18. The dry years in the Flagstaff area tree-growth analyze best on 14- and 21-year cycles with major droughts at about 150-year intervals and minor droughts at 40- or 50-year intervals.

19. The extension of the cycles observed in the last 200 years in the Flagstaff area indicates possible large growth of trees in the 1930's and 1950's, with depressions in the early and late 1940's.

It is recognized that much of this work is new and that time is needed to test and improve it, but it is hoped that these preliminary results are not greatly in error.

APPENDIX

TABLES OF GROUP AVERAGES, STANDARDIZED

ARIZONA ZONE

FLAGSTAFF (FL), APPENDIX, VOLUME I, PAGE 113

Flagstaff University Section (FLU), 500-year trees

A.D.	0	1	2	3	4	5	6	7	8	9
1700	0.98	1.07	1.00	0.86	1.03	1.22	1.40	0.77	0.69	0.85
1710	1.01	0.79	0.85	0.85	1.05	1.08	1.17	1.08	1.20	1.03
1720	1.27	1.04	0.93	1.34	1.00	1.22	1.57	0.80	0.94	0.64
1730	1.04	0.84	0.95	0.85	0.90	0.51	0.84	0.76	1.14	0.76
1740	0.93	1.11	1.11	1.08	1.13	1.11	1.39	1.09	0.64	1.21
1750	0.91	0.75	0.45	0.69	0.61	0.72	0.65	0.83	1.15	0.98
1760	1.05	1.10	1.37	1.24	1.54	1.23	0.79	0.96	0.82	0.76
1770	0.95	1.12	0.88	0.67	0.85	0.97	0.88	0.97	0.60	0.60
1780	0.62	0.72	0.51	1.01	1.32	0.62	0.70	1.11	0.95	0.67
1790	0.90	0.86	0.99	1.21	1.20	0.92	0.90	0.98	0.79	0.95
1800	0.76	0.56	0.97	0.85	0.61	0.77	0.99	0.69	0.86	0.96
1810	0.98	1.18	1.09	0.49	0.94	0.86	0.80	0.67	0.60	0.85
1820	0.69	0.61	0.53	0.62	0.64	0.92	1.12	0.87	0.96	0.85
1830	0.96	0.82	0.98	1.02	0.70	0.80	0.80	0.80	0.76	0.92
1840	1.00	0.70	0.72	0.82	0.74	0.67	0.58	0.40	0.80	0.91
1850	1.00	0.77	1.13	1.29	1.09	1.02	1.06	0.84	1.11	0.88
1860	0.98	0.92	1.07	0.78	0.70	0.86	1.04	1.02	1.33	1.04
1870	1.14	0.84	0.94	0.82	1.05	1.06	0.72	0.70	0.85	0.75
1880	0.69	1.01	0.88	0.86	0.81	1.10	0.80	0.86	0.95	0.96
1890	1.12	1.12	0.98	1.36	1.21	1.05	1.34	1.18	1.26	0.95
1900	0.71	0.83	0.80	0.79	0.63	1.14	1.24	1.28	1.64	1.80
1910	1.68	1.66	1.42	1.19	1.42	1.36	1.36	1.00	0.95	....

Fort Valley (FV), 6 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1680	....	....	....	....	....	....	0.50	0.83	0.85	0.90
1690	0.86	0.82	0.90	1.06	0.85	0.76	0.89	1.43	1.30	1.61
1700	1.24	1.35	0.97	1.05	0.88	0.70	1.20	1.36	1.28	1.61
1710	1.91	1.56	1.54	1.71	1.66	1.54	1.04	1.48	1.59 +	1.73
1720	1.90	1.33	1.12	1.29	0.95	1.69 +	1.65	0.92	0.83	0.43
1730	1.04	0.82	1.48	1.44	1.18	0.38	1.11	0.90	1.04	0.81
1740	1.33	1.15	0.88	1.54	1.64	1.84	1.98	1.20	0.52	1.26
1750	0.77	0.85	0.45	0.79	0.95	0.83	0.84	0.87 +	1.28	1.03
1760	1.30	1.36	1.33	0.76	1.46	1.07	1.29	1.10	1.01	10.5
1770	1.05	1.50	1.48	0.69 +	0.83	1.03	1.04	0.81	0.48	0.85
1780	0.47	0.60	0.38	0.87	1.28	1.06	1.55	1.93	1.29	1.32
1790	1.16	1.12	1.17	1.62	1.43	1.17	0.64	0.95	0.77	1.34
1800	0.78	0.81	1.27	1.05	0.98	0.82	1.04	0.93	0.84	1.01
1810	0.88	1.01	0.94	0.44	0.51	0.76	0.79	0.65	0.58	0.97
1820	0.72	0.71	0.56	0.66	0.81	1.09	1.47 +	1.17	1.39	0.75
1830	0.92	1.15	1.32	1.37	1.30	1.46	0.83 +	0.97 +	1.21	1.10
1840	1.03	0.54	0.57	0.49	0.81	0.65	0.57	0.36	0.83	1.07
1850	1.14	0.58	1.18	1.17	1.24	1.19	0.78	0.74	1.08−	0.79
1860	0.92 +	0.96	1.09	0.76	0.66	0.87−	1.55	1.38	1.90	1.26
1870	1.30	1.10	1.26	1.24	1.53	1.17	0.87	0.81	0.91	0.37
1880	0.73	0.65	0.76	0.75	0.57	0.80	0.76	0.75	1.06	1.25
1890	1.14	1.01	1.07	1.09	0.94	0.67	0.89	0.93	1.14	0.80
1900	1.02 +	1.43	1.03	1.49 +	1.05	1.58	1.62	1.94	2.30	2.19
1910	1.49 +	1.25	1.39	1.05 +	1.30	1.20	1.57	1.54	0.95	1.80
1920	0.90	....	....	....	....	....	....	....	....	....

Flagstaff High (FLH), 10 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1630	....	....	....	....	....	....	....	4.60	3.80	2.90
1640	3.60	4.40	1.70	2.50	3.00	2.70	3.50	3.80	3.00	3.50
1650	4.30	4.00	3.80	4.20	3.50	4.20	3.90	2.50	2.00	2.30
1660	1.20	0.30	1.00	0.90	0.80	0.80	0.80	0.50	0.70	0.50
1670	0.50	0.50	1.00	1.00	1.10	0.60	0.90	1.10	2.10	1.50
1680	1.80	1.70	1.80	2.50	3.30	2.40	1.90?	2.90	2.00	2.50
1690	2.20	1.50	2.30	1.70	1.60	1.80	1.50	1.30	1.40	2.20
1700	1.70	1.60	1.40	0.90	1.60	2.10	1.60	1.40	1.20	2.00
1710	2.20	1.20	1.20	1.30	1.40	1.40	1.40	0.90	1.10	1.40
1720	1.40	1.30	1.20	1.30	1.20	1.00	1.40	1.60	1.30	1.40
1730	1.30	1.30	1.40	1.40	1.10	0.70	1.20	1.00	1.30	0.90
1740	0.40	1.00	2.00	1.00	1.00	1.10	1.10	1.00	0.50	0.90
1750	0.70	1.10	0.90	1.00	0.80	0.70	1.00	0.90	0.60	0.80
1760	0.80	0.80	0.90	0.80	0.70	0.70	0.80	0.80	0.70	0.70
1770	1.15	2.10	2.55	1.70	2.15	2.15	1.65	1.90	2.05	1.50
1780	1.97	1.93	1.83	2.53	2.37	2.07	2.26	2.63	1.97	2.23
1790	2.40	3.08	2.43	1.83	2.08	1.55	2.12	2.33	2.10	2.37
1800	2.32	2.21	2.14	2.40	2.31	2.09	2.51	1.99	2.21	2.29
1810	2.27	2.04	2.11	1.40	1.87	1.41	1.36	1.44	1.43	1.63
1820	1.51	1.36	1.11	1.36	1.57	1.74	1.86	1.27	1.24	1.53
1830	1.57	1.40	1.67	1.23	1.84	1.47	1.24	1.68	1.73	1.84
1840	1.95	1.40	1.16	1.61	2.08	1.84	1.57	1.61	1.43	1.79
1850	1.58	2.03	2.17	2.45	1.80	2.00	1.94	2.49	2.41	1.69
1860	2.18	1.79	1.87	1.85	1.71	1.87	1.45	1.72	1.92	2.18
1870	2.25	2.01	1.63	2.05	1.58	2.10	1.62	1.81	1.85	2.27
1880	1.20	1.60	1.53	1.81	1.49	1.76	1.61	1.80	1.74	1.92
1890	2.04	1.72	1.94	1.58	1.80	1.85	1.03	1.31	1.45	1.09
1900	1.23	1.18	1.20	1.49	1.55	1.25	1.42	1.74	1.95	1.99
1910	1.87	1.62	1.60	1.70	1.75	1.50	1.22	1.33	1.29	1.18
1920	1.18	1.06	1.23	1.12	0.52	....	....	....	....	....

Flagstaff Shadow (SH), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1710	....	....	....	....	....	....	....	4.80	6.10	5.40
1720	5.90	3.60	4.00	0.90	2.60	3.80	4.10	3.30	3.50	2.00
1730	3.90	2.20	2.60	2.70	4.50	1.20	2.50	1.30	0.40	1.10
1740	2.30	2.10	2.10	3.90	4.30	4.10	4.60	3.70	1.00	3.90
1750	2.20	2.30	0.50	1.30	2.90	2.50	3.50	3.00	3.90	2.95
1760	2.60	1.85	2.40	1.20	3.05	2.45	2.85	1.95	2.20	1.95
1770	1.95	1.65	1.75	0.45	0.80	1.20	1.65	1.00	0.70	0.50
1780	0.45	1.05	1.73	1.33	2.00	0.77	0.53	1.80	0.70	1.43
1790	0.83	1.53	2.23	3.33	2.23	2.45	1.80	2.08	1.33	2.30
1800	0.80	0.83	1.45	0.43	1.03	0.70	1.33	1.23	1.78	1.30
1810	1.53	1.70	1.85	0.50	0.55	0.90	1.62	1.15	0.75	10.8
1820	0.30	1.40	0.62	0.70	1.60	1.80	2.15	2.38	2.76	1.66
1830	2.52	2.45	2.45	2.20	2.18	2.23	1.78	1.55	2.15	2.55
1840	2.15	1.30	1.63	1.38	1.98	1.53	0.65	0.75	1.48	1.60
1850	1.98	1.45	2.25	2.00	1.80	1.80	1.32	0.58	0.80	0.75
1860	1.13	1.35	1.55	1.13	1.08	1.35	2.50	2.75	3.02	2.70
1870	2.23	1.50	1.13	0.63	0.87	0.97	0.65	0.60	0.72	0.60
1880	0.42	0.60	0.75	1.30	1.52	1.98	1.16	1.12	1.52	1.54
1890	1.78	1.76	1.74	1.68	1.60	1.58	0.74	1.10	1.12	0.68
1900	0.70	0.68	0.32	1.38	0.94	1.40	2.48	3.02	2.90	3.28
1910	2.84	2.40	2.02	1.32	2.08	2.06	2.15	1.38	2.06	2.76
1920	2.40	2.02	2.04	1.76	*1.28	....	....	....	....	....

* Incomplete.

Flagstaff Northeast (NE), 4 trees

(Dates prior to 1685 marked "doubtful")

A.D.	0	1	2	3	4	5	6	7	8	9
1670	....	....	....	....	....	....	....	1.10	1.08	2.70
1680	....	2.55	1.33	1.83	0.42	1.05	1.10	2.05	1.90	1.90
1690	1.15	1.92	2.24	2.22	1.60	1.60	0.82	0.65	1.68	1.40
1700	0.45	2.20	0.87	0.38	0.68	1.05	0.55	0.83	0.42	0.55
1710	1.20	1.15	1.50	1.65	1.75	1.95	2.30	2.50	3.48	4.70
1720	4.45	2.40	0.95	1.78	1.46	2.37	4.23	2.76	2.29	1.14
1730	1.13	1.38	1.49	0.56	1.37	0.39	1.26	0.74	1.36	1.02
1740	1.70	1.89	1.08	2.31	2.09	2.72	3.83	3.35	1.10	2.11
1750	1.47	1.53	0.83	1.49	1.82	0.68	1.80	2.03	3.02	3.53
1760	3.42	1.77	2.31	1.18	1.40	1.85	1.98	1.66	1.79	1.39
1770	1.21	1.51	0.90	0.64	0.79	0.93	1.41	1.34	0.75	0.91
1780	0.79	0.73	0.89	1.75	1.33	0.54	0.62	1.27	0.85	0.77
1790	1.00	1.24	1.56	2.12	1.84	1.67	1.83	1.41	0.80	1.08
1800	0.63	0.41	0.47	0.45	1.08	0.46	1.02	0.89	1.12	1.14
1810	1.22	1.55	1.37	0.60	1.44	1.81	1.67	1.67	1.43	1.36
1820	0.87	1.15	0.91	1.31	1.54	1.53	1.98	1.63	2.01	1.21
1830	1.64	1.61	1.59	1.64	0.89	1.38	1.18	1.02	1.59	1.71
1840	1.88	1.46	0.68	1.14	1.55	0.31	0.61	0.12	0.85	0.87
1850	1.06	0.77	1.09	1.07	0.71	0.90	0.74	0.09	0.77	0.40
1860	0.63	0.60	0.58	0.49	0.26	0.57	0.65	0.83	1.20	1.19
1870	0.77	0.40	0.43	0.57	0.62	0.80	0.61	0.26	0.35	0.25
1880	0.33	0.10	0.35	0.29	0.43	0.77	0.63	0.68	0.71	0.72
1890	0.97	0.85	1.12	0.85	1.07	0.95	0.59	0.84	0.70	0.35
1900	0.50	0.41	0.13	0.48	0.13	0.66	0.83	1.32	1.38	1.62
1910	1.51	1.74	1.35	0.94	1.24	1.11	1.12	1.20	1.22	1.29
1920	1.38	1.25	1.27	....	....	....	....	....	....	....

Grand Canyon (GC), 7 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1710	....	....	....	....	....	....	1.25	1.55	2.95	1.20
1720	2.00	2.15	0.60	1.90	0.60	0.90	1.50	1.25	0.95	0.50
1730	0.80	1.15	2.00	1.10	0.60	0.30	0.60	0.45	1.10	0.40
1740	1.25	1.30	0.90	1.30	1.05	1.20	2.05	2.12	0.67	1.90
1750	1.25	0.92	0.35	0.47	0.48	0.47	0.67	0.82	1.27	0.95
1760	1.15	0.92	1.28	0.93	1.83	1.03	1.13	1.35	1.60	0.93
1770	0.77	1.50	1.27	0.58	0.80	0.90	1.30	0.95	0.38	0.92
1780	1.23	0.93	0.50	0.98	1.50	0.53	0.95	1.42	0.78	0.93
1790	0.80	1.13	0.95	2.00	0.76	1.22	0.84	0.70	0.53	1.09
1800	0.45	0.45	0.81	0.44	0.71	0.62	0.44	0.78	0.81	0.64
1810	0.30	0.74	0.96	0.24	0.52	0.50	0.73	0.65	0.31	0.52
1820	0.28	0.61	0.25	0.39	0.52	0.86	0.89	0.87	1.03	0.36
1830	0.49	0.74	0.68	0.85	0.60	0.87	0.54	0.86	0.81	1.11
1840	1.16	0.69	0.42	0.44	0.75	0.13	0.23	0.07	0.55	0.83
1850	0.89	0.61	0.74	0.74	0.87	0.96	0.79 +	0.66	0.84	0.49
1860	0.51	0.44	0.83	0.52	0.31	0.63	1.18	0.85	1.66	1.33
1870	0.80	0.66 −	0.61	0.45	0.90	0.88	0.55	0.48	0.79	0.27
1880	0.28	0.25	0.30	0.35	0.69 +	1.08	0.97	0.50	1.16 +	1.18
1890	1.68	1.66 +	1.66	1.41	0.84	1.17	0.32 +	0.86	0.79 +	0.16 +
1900	0.28 +	0.35	0.37	0.67	0.06	0.61	1.01	1.32	1.23	2.17
1910	1.08	1.39 +	1.07	0.67	1.19	1.07	1.14	0.82	0.39 +	0.89

Dixie Forest (DF), 10 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1610	....	....	....	....	....	....	1.56	1.62	2.20	1.26
1620	1.26	2.26	1.06	1.76	1.00	1.70	1.95	1.85	2.20	2.40
1630	1.85	1.50	1.40	2.50	2.30	2.35	2.60	1.65	2.15	1.40
1640	2.20	1.75	2.25	2.30	2.50	2.20	1.65	2.35	1.85	2.10
1650	2.30	3.10	3.75	1.35	2.60	1.50	2.05	2.20	2.45	2.25
1660	2.28	2.70	2.70	2.05	2.45	1.80	1.85	2.40	1.80	1.95
1670	1.30	2.40	2.45	2.10	2.35	1.65	1.50	2.10	1.75	1.75
1680	2.10	2.15	1.50	2.90	1.60	2.50	1.40	2.10	1.65	1.75
1690	1.15	1.65	1.80	1.65	2.10	2.15	1.75	1.55	1.65	1.95
1700	2.10	1.95	1.85	1.30	1.65	2.10	2.15	0.70	0.55	0.95
1710	1.30	1.55	0.95	0.85	1.10	1.05	1.42	1.35	1.52	1.70
1720	2.10	1.85	1.87	1.80	2.37	1.77	2.31	1.74	1.79	1.02
1730	1.56	1.71	1.21	1.50	1.44	0.35	1.32	1.09	1.35	1.24
1740	1.52	1.56	1.14	1.40	1.45	1.51	1.76	1.76	1.35	1.94
1750	1.26	1.46	0.89	1.21	1.19	1.24	1.02	1.41	1.15	1.11
1760	1.24	1.15	1.09	0.77	0.89	1.13	1.34	1.27	1.11	1.27
1770	1.36	1.30	1.16	1.40	1.46	1.46	1.40	1.17	1.39	1.33
1780	1.38	1.21	1.01	1.22	1.78	1.12	1.14	1.50	1.13	1.68
1790	1.46	1.45	1.62	1.36	1.56	1.17	1.26	1.36	1.18	1.42
1800	1.24	1.44	1.60	1.06	1.24	1.43	1.27	1.24	1.28	1.47
1810	1.32	1.52	1.27	1.16	1.34	1.24	1.30	1.28	1.27	1.30
1820	0.96	1.30	0.94	0.92	0.97	1.26	1.20	1.22	1.53	1.40
1830	1.23	1.48	1.70	1.60	1.16	1.22	1.01	1.20	0.98	1.18
1840	1.33	0.98	0.90	1.04	1.18	1.03	1.17	0.94	1.03	1.53
1850	1.34	1.04	1.12	1.30	1.26	1.35	1.14	1.26	1.22	1.18
1860	1.15	1.02	1.34	1.37	0.91	1.02	1.43	1.41	1.45	1.40
1870	1.61	1.22	1.20	1.10	1.38	1.34	1.00	1.30	1.14	0.68
1880	0.85	0.97	1.17	1.18	1.19	1.58	1.14	1.44	1.42	1.16
1890	1.30	1.45	1.43	1.37	1.52	1.40	1.34	1.43	1.50	1.34
1900	1.30	1.57	1.34	1.38	1.59	1.46	1.59	1.79	1.78	1.66
1910	1.79	1.64	1.60	1.55	1.63	1.61	1.67	1.39	1.34	1.44
1920	1.17	1.21	1.35	1.00	....	....	....	....	....	....

Rim High (RH), 2 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1690	....	....	....	....	....	....	....	0.98	1.22	1.58
1700	1.20	1.26	1.05	1.22	0.75	0.98	1.04	0.55	0.79	1.31
1710	1.42	0.66	0.92	1.19	1.12	1.17	0.97	0.96	1.22	0.98
1720	1.26	0.92	0.60	1.13	0.90	0.82	1.09	0.53	0.70	0.55
1730	0.69	0.60	0.78	0.47	1.00	0.37	0.84	0.74	0.66	0.53
1740	1.03	0.63	0.72	0.80	0.56	0.86	1.12	0.93	0.25	0.79
1750	0.91	0.66	0.40	0.65	0.92	1.04	0.86	0.75	0.86	1.15
1760	1.22	0.70	0.90	0.90	1.55	1.30	1.50	1.80	1.20	1.00
1770	1.45	1.40	0.80	0.90	0.85	0.60	1.00	0.85	1.06	0.83
1780	1.00	1.10	0.63	0.82	1.69	0.80	1.20	1.40	1.08	0.79
1790	0.71	0.79	0.88	1.20	1.01	0.88	0.70	0.65	0.53	0.70
1800	0.65	0.60	0.98	0.93	1.00	1.18	0.75	0.96	1.00	0.92
1810	0.81	1.12	0.87	0.68	0.65	0.90	0.83	0.55	0.69	0.51
1820	0.56	0.55	0.51	0.41	0.45	0.57	0.63	0.48	0.48	0.35
1830	0.52	0.46	0.48	0.45	0.65	0.58	0.70	0.70	0.80	0.73
1840	0.72	0.44	0.57	0.68	0.71	0.29	0.70	0.42	0.68	0.80
1850	0.70	0.70	0.91	0.63	0.70	0.55	0.78	0.61	0.76	0.72
1860	0.72	0.80	0.65	0.66	0.68	0.82	1.20	0.76	1.10	0.48
1870	0.78	0.76	0.73	0.43	0.83	0.83	0.72	0.81	0.98	0.65
1880	0.78	0.80	0.66	0.80	0.82	0.72	0.52	0.80	0.82	0.70
1890	0.85	0.63	0.59	1.02	0.50	0.62	0.88	0.79	0.78	0.78
1900	0.50	0.75	0.48	0.76	0.25	0.75	0.76	0.84	1.06	0.90
1910	0.70	0.80	0.75	0.58	0.80	0.68	0.62	0.82	0.52	0.66
1920	0.59	0.76	0.55	....	....	....	....	....	....	....

Rim Low (RL), 2 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1770	1.00	1.43	1.43	0.98	1.02	1.10	1.35	1.27	0.84	0.71
1780	0.68	0.75	0.51	0.77	1.49	0.92	0.95	1.35	0.97	0.99
1790	0.93	1.27	1.14	1.69	1.00	0.84	0.70	0.95	0.65	0.87
1800	0.72	0.71	0.84	0.50	0.79	0.68	0.83	1.00	1.05	0.95
1810	0.49	1.18	1.16	0.56	0.94	1.13	0.65	0.85	0.77	0.41
1820	0.12	0.70	0.36	0.28	0.85	0.75	1.13	1.43	1.50	1.53
1830	1.29	0.61	1.50	1.22	0.86	1.06	1.08	0.82	0.71	1.52
1840	1.46	0.78	0.78	0.84	0.89	0.62	0.63	0.27	0.83	0.75
1850	0.60	0.78	1.32	0.85	0.73	0.96	0.55	0.28	0.77	0.38
1860	0.58	0.44	0.62	0.39	0.24	0.70	0.60	0.90	1.41	1.44
1870	0.95	0.74	0.66	0.48	0.39	0.86	0.70	0.68	0.93	0.32
1880	0.58	0.41	0.35	0.45	0.92	1.38	0.92	0.78	1.36	1.08
1890	1.25	1.42	0.90	1.26	0.39	1.19	0.44	0.84	0.84	0.60
1900	0.36	0.79	0.06	0.42	0.08	0.95	0.98	1.31	1.85	1.49
1910	1.31	1.41	1.32	0.63	1.45	1.01	1.12	1.28	1.05	1.22
1920	1.33	1.02	....	....	....	....	....	....	....	....

Cibecue (J), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1650	....	....	1.02	1.43	1.10	0.75	1.13	0.86	0.43	0.66
1660	0.80	1.09	1.12	1.40	1.33	1.37	1.11	1.00	0.75	0.63
1670	0.21	1.02	0.77	1.00	0.88	0.80	0.90	0.87	0.67	0.95
1680	1.30	1.43	0.92	1.43	0.27	0.13	1.20	1.40	1.60	1.55
1690	1.66	1.20	1.60	1.05	1.80	1.70	1.00	1.70	0.93	2.83
1700	1.03	0.98	1.24	0.87	1.13	1.35	1.34	0.35	0.55	0.72
1710	1.24	0.68	0.71	0.69	1.35	0.62	0.40	0.90	1.17	0.96
1720	1.10	1.02	0.66	1.03	0.44	0.95	1.15	0.90	0.75	0.33
1730	0.73	0.41	0.90	0.48	0.85	0.18	0.72	0.83	1.10	0.53
1740	1.28	1.16	0.73	1.00	0.82	1.11	1.35	1.62	0.80	1.96
1750	1.33	0.58	0.18	0.40	0.65	0.45	0.48	0.38	0.68	0.72
1760	0.66	0.60	1.18	0.40	1.59	0.81	1.38	0.92	1.16	0.93
1770	0.99	1.22	0.96	0.29	0.86	0.82	0.81	0.62	0.39	0.58
1780	0.27	0.36	0.12	0.59	1.08	0.43	0.69	1.10	0.67	0.59
1790	0.52	0.82	1.08	1.77	0.86	1.06	0.89	0.43	0.52	0.61
1800	0.38	0.27	0.43	0.12	0.47	0.29	0.36	0.44	0.51	0.47
1810	0.29	0.50	0.47	0.39	0.41	0.53	0.68	0.58	0.40	0.12
1820	0.04	0.34	0.03	0.28	0.28	0.48	0.33	0.13	0.72	0.44
1830	0.38	0.42	0.43	0.68	0.62	0.50	0.52	0.44	0.62	0.91
1840	0.68	0.42	0.40	0.33	0.70	0.20	0.20	0.12	0.15	0.46
1850	0.55	0.45	0.82	0.73	0.43	0.47	0.88	0.57	0.88	0.55
1860	0.90	0.49	1.03	0.77	0.26	0.92	0.91	1.01	1.28	1.23
1870	0.84	0.38	0.83	0.38	0.47	0.78	0.57	0.49	0.44	0.60
1880	0.43	0.41	0.42	0.49	0.57	0.66 +	0.64	0.46	0.57	0.59
1890	0.90	0.82	0.78	0.41	0.20	0.34	0.44	0.40	0.40	0.37
1900	0.12	0.35	0.10	0.21	0.12	0.47	0.71	0.76	0.91	1.01
1910	0.76	1.04	0.65	0.42	1.03	0.84	0.96	1.17	0.90	0.88
1920	0.67	....	....	....	....	....	....	....	....	....

Pinal (PNL), 3 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1760	0.73	1.10	1.35	0.72	1.30	0.92	0.65	0.60	0.90	0.80
1770	0.80	1.15	0.80	0.45	0.55	0.70	0.42	0.50	0.65	0.60
1780	0.63	0.55	0.35	0.58	0.68	0.63	0.78	1.05	0.55	0.92
1790	0.75	0.58	0.73	0.60	0.68	0.55	0.68	0.65	0.75	0.98
1800	0.95	0.75	0.95	0.85	0.78	0.96	0.69	0.64	0.86	0.93
1810	0.67	0.46	0.50	0.42	0.59	0.56	0.47	0.62	0.44	0.38
1820	0.27	0.69	0.36	0.33	1.08	1.11	0.98	1.00	1.23	0.88
1830	1.36	0.92	1.37	1.37	0.83	0.90	0.87	0.69	0.90	1.14
1840	0.89	0.47	0.84	1.09	1.36	0.84	0.90	0.44	1.15	1.00
1850	1.35	1.52	2.17	1.11	0.94	0.84	0.86	0.79	1.07	0.73
1860	0.91	0.75	0.94	0.42	0.33	0.80	1.15	0.55	0.95	0.99
1870	0.57	0.43	0.56	0.44	0.49	0.88	1.03	0.78	0.95	0.90
1880	0.48	0.95	0.80	0.60	0.85	0.87	0.50	0.64	0.48	0.41
1890	0.87	0.79	0.36	0.51	0.47	0.46	0.57	1.07	0.83	1.01
1900	0.015	0.36	0.73	0.56	0.42	1.09	1.28	1.22	2.14	2.13
1910	0.66	0.68	0.64	0.40	0.54	0.68	0.53	0.41	0.27	0.32
1920	0.36	0.47	0.43	0.23	....	....	....	....	....	....

Santa Catalina (SC), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1560	....	....	....	....	....	....	....	1.02	1.46	1.85
1570	1.47	1.67	0.87	1.20	0.98	1.42	1.42	1.27	1.03	0.88
1580	1.08	1.63	1.46	1.10	1.11	1.60	1.50	1.20	1.20	1.30
1590	0.68	0.95	1.17	1.16	1.04	1.10	1.11	1.40	1.22	1.14
1600	1.75	1.44	1.51	1.20	0.93	1.38	0.91	1.45	1.29	1.24
1610	1.60	1.10	0.80	1.23	1.21	0.87	1.39	1.19	0.98	1.43
1620	1.31	0.85	0.91	0.81	0.68	0.47	0.19	0.26	0.30	0.39
1630	0.65	0.78	1.30	2.02	1.73	1.10	1.56	1.16	1.03	1.35
1640	1.21	0.90	0.96	0.72	0.68	0.83	1.07	1.65	1.53	1.00
1650	1.81	0.67	0.72	0.89	1.00	1.40	1.00	0.59	0.65	0.61
1660	0.34	0.65	0.41	0.51	0.55	0.80	1.34	1.04	2.02	1.86
1670	1.80	1.74	1.48	1.49	1.19	1.52	1.54	1.25	1.71	0.94
1680	0.71	1.51	1.05	1.10	1.15	0.87	1.17	1.22	1.44	0.96
1690	1.48	1.13	1.15	1.06	0.74	0.48	0.78	1.06	0.43	1.08
1700	0.89	0.80	1.07	1.12	1.09	0.81	0.79	0.85	0.99	0.96
1710	0.82	0.58	0.70	0.85	0.65	0.59	0.48	0.59	0.68	0.85
1720	0.66	0.84	0.78	0.79	0.84	0.81	0.83	0.91	0.83	1.46
1730	1.36	1.51	1.51 +	1.39	1.11	1.00	1.06	1.20	1.17	0.88
1740	0.81	1.21	0.95	1.08	0.77	0.77	0.80	0.76	0.41	0.73
1750	0.74 −	0.68 +	0.51	0.56	0.80	0.91	0.82	0.98	0.96	1.01
1760	0.86	1.06	0.98	1.03	1.18	1.16	1.12	1.10	1.01	0.96
1770	1.09	1.02	1.04	0.98	1.07	1.14	1.14	1.19	1.38	1.09
1780	1.17	1.32	1.01	1.19	1.18	1.13	0.79 +	0.78 −	0.75	0.65
1790	0.72	0.97	1.29	1.29	1.39	1.13	0.87	0.95	0.83	0.99
1800	1.20	1.11	0.95	0.99 +	1.09	1.21	1.41	1.21	1.04	1.37
1810	1.29	1.21	1.04	1.10	1.32	1.33	1.32	1.03	0.80	0.73
1820	0.85	0.74	0.65	0.83	0.84	0.91	1.08	1.01	0.90	1.12
1830	1.28	0.82	1.24	0.82	0.56	0.94	0.67	0.82	0.93	1.08
1840	1.14	0.94	0.94	1.34	1.59	1.80	1.20	1.42	1.38	1.08
1850	1.19	0.72	0.96	1.16	0.82	0.51	0.78	0.97	0.95 −	0.69 −
1860	1.13	1.07	0.74	0.89	0.70	0.50	0.83	0.51	0.54	0.53
1870	0.64	0.74	0.89	0.79	0.77 +	0.97	0.89	0.80	1.13	1.35
1880	0.94 +	0.88	1.02	0.91	1.10	1.18	0.88	0.82	1.01	0.98
1890	0.95	0.68	0.74	0.96	0.81	0.80	0.88	0.70	1.09	0.89
1900	0.78	0.89	0.76	0.76	0.74	0.96	0.53	0.74 +	0.95	0.68
1910	0.46	0.57	0.58	0.62	0.83	0.45	0.65	0.79	0.52	0.75
1920	0.79 +	....	....	....	....	....	....	....	....	....

Santa Rita (SR), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1670	0.82	0.52	0.47	0.64	0.74	1.00	2.18	1.20	1.87	1.00
1680	1.07	1.20	1.09	0.95	1.14	1.11	1.13	1.41	1.43	0.85
1690	0.59	0.77	0.98	1.12	1.38	0.80	0.72	1.05	1.18	1.27
1700	1.00	1.20	1.00	1.58	1.30	1.04	0.91	0.85	1.12	1.14
1710	1.30	0.72	0.72	0.44	1.04	0.84	0.85	1.12	1.25	1.22
1720	1.31	1.06	1.06	1.10	1.40	1.18	1.51	0.61	1.20	1.02
1730	0.97	1.61	1.68	0.86	0.87	0.56	1.18	0.88	0.87	0.58
1740	0.86	0.78	1.03	1.93	1.74	1.21	1.42	1.70	0.62	0.46
1750	0.78	0.12	0.69	0.40	0.42	0.66	0.78	1.00	1.10	0.76
1760	1.08	1.22	0.66	1.11	1.01	0.79	1.04	1.04	1.13	0.98
1770	0.98	0.67	0.90	0.53	0.50	0.55	0.60	0.75	0.59	0.70
1780	0.80	0.67	1.02	0.90	1.10	0.70	0.62	0.81	1.01	0.99
1790	0.69	0.66	0.85	0.83	0.57	0.66	0.78	0.39	0.39	1.08
1800	0.56	0.23	0.77	1.03	1.18	1.28	1.11	1.22	0.87	1.30
1810	1.58	1.31	1.54	1.06	1.51	1.49	1.47	0.97	1.22	0.41
1820	0.61	0.62	0.68	0.82	0.95	0.89	1.50	1.42	1.45	1.32
1830	1.35	1.14	1.30	1.05	0.78	0.97	0.83	0.95	0.96	1.41
1840	1.53	0.84	0.62	1.12	1.55	1.32	1.05	0.39	0.58	0.78
1850	0.95 +	0.87	1.03	1.32	1.26	1.33	1.29	0.97	1.00	1.12
1860	1.23	1.17	0.86	0.81	0.72	0.85	0.79	0.68	0.94	0.98
1870	0.80	0.77	0.65	0.78	0.64	0.77	0.44	0.88 +	0.80	0.75
1880	0.53	1.02	1.22	1.19	1.04	1.05	0.46	0.54	0.92	0.76
1890	0.75	0.66	0.39 +	0.37	0.53	0.43	0.97	0.90	1.22	1.21
1900	0.77	0.91	0.63	1.13	0.71	1.24	1.09	1.25	1.39	1.13
1910	0.84	1.30	0.71	0.96	1.30	0.92	1.06	1.15	0.91	1.19
1920	0.84	0.62	....	....	....	....	....	....	....	....

ROCKY MOUNTAIN ZONE

Yellowstone (Y), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1690	....	....	....	1.00	1.16	1.16	0.88	0.66	1.02	0.77
1700	0.74	1.09	1.00	1.12	0.98	1.06	0.95	0.79	1.00	1.29
1710	1.00	0.95	1.22	1.16	1.16	1.09	1.12	0.81	0.83	0.87
1720	0.89	0.87	0.80	1.06	0.97	1.00	0.95	1.06	1.26	1.23
1730	1.02	0.85	1.03	1.21	1.24	0.95	0.93	1.46	1.08	1.11
1740	1.00	1.15	1.03	0.85	0.75	1.05	1.13	1.17	1.20	1.18
1750	1.04	1.05	1.13	1.13	0.91	0.95	1.06	1.05	1.11	1.50
1760	1.36	0.98	0.98	1.11	1.01	1.11	1.01	1.25	1.37	1.35
1770	1.10	1.04	1.16	1.21	1.36	1.00	1.43	1.29	1.28	1.17
1780	1.43	1.00	0.87	0.86	0.97	0.78	0.94	1.16	1.03	1.29
1790	1.03	1.33	1.27	1.35	1.17	1.38	1.16	0.90	0.98	0.84
1800	1.00	0.94	1.00	0.91	1.10	0.93	0.89	0.75	1.03	0.79
1810	0.92	0.88	0.93	1.12	0.91	1.26	1.24	1.48	1.36	1.27
1820	1.40	1.12	1.04	0.96	1.02	0.96	1.15	1.33	1.11	1.13
1830	1.06	1.13	0.97	0.97	1.22	1.14	1.14	1.18	1.08	1.19
1840	1.04	1.35	1.47	1.78	1.55	1.10	1.32	1.02	0.94	1.04
1850	1.00	1.09	0.83	1.09	1.08	0.82	0.92	1.12	0.94	1.01
1860	1.13	1.37	1.01	1.10	0.87	0.83	1.04	1.00	1.15	0.98
1870	0.88	0.84	0.89	0.86	0.97	0.94	0.95	1.11	1.17	1.38
1880	1.12	1.17	1.20	0.75	1.05	1.09	1.09	1.12	1.26	1.15
1890	1.18	1.19	1.14	1.11	1.15	1.12	0.92	1.17	0.95	0.74
1900	1.03	0.96	0.74	0.83	0.83	0.98	0.77	0.90	1.02	0.98
1910	1.16	1.06	0.99	1.09	1.08	0.89	0.84	0.79	0.88	0.87
1920	0.87	....	....	....	....	....	....	....	....	....

Laramie, Wyoming (LW), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1750	....	....	....	....	1.95	1.20	0.55	0.35	0.65	0.80
1760	0.80	1.75	0.95	1.15	0.95	1.10	1.20	1.35	1.70	1.80
1770	0.90	1.35	1.00	0.80	1.05	1.20	1.20	0.50	1.50	1.50
1780	1.60	1.90	1.00	1.30	2.15	1.95	1.10	2.05	0.85	0.50
1790	1.40	1.30	1.15	1.70	2.00	1.25	1.20	0.30	0.45	1.60
1800	1.60	1.30	2.40	2.55	0.70	0.45	0.95	0.50	1.05	0.85
1810	1.30	1.25	1.05	1.05	1.10	1.00	1.05	1.20	1.00	1.25
1820	0.55	1.20	1.65	1.25	0.60	1.40	1.10	1.05	1.85	1.32
1830	0.96	0.90	0.94	1.12	1.16	1.37	1.58	1.78	1.69	1.84
1840	1.52	1.46	0.53	1.89	1.48	0.86	1.04	0.61	0.57	0.98
1850	1.05	0.72	1.14	1.56	1.09	0.59	0.59	0.59	1.16	1.31
1860	1.51	0.43	1.63	0.56	1.05	0.92	1.54	1.53	1.68	1.86
1870	1.63	0.91	1.75	1.31	0.66	1.56	1.36	0.65	1.63	0.92
1880	0.26	0.18	0.99	0.78	0.81	0.98	0.82	0.78	1.19	1.32
1890	1.03	1.83	1.24	0.93	0.93	1.21	1.08	1.46	1.42	1.21
1900	0.92	1.39	1.18	1.66	1.65	1.46	2.14	1.99	1.84	1.72
1910	1.43	1.18	1.31	1.74	1.46	1.93	1.00	1.55	1.48	0.58
1920	1.47	1.60	1.15	1.62	1.41	....	....	....	....	....

Clements' Pike's Peak (C), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1770	....	....	....	....	....	....	....	....	1.41	1.86
1780	1.78	2.38	2.16	1.26	1.62	1.41	1.79	1.75	2.00	1.41
1790	2.27	2.20	2.56	2.52	2.42	2.36	2.46	1.91	1.83	1.23
1800	1.73	1.14	1.65	2.13	1.60	1.12	1.77	1.77	1.32	1.53
1810	1.60	1.55	1.92	1.65	1.31	1.71	1.95	1.68	1.53	1.71
1820	1.54	1.31	1.19	1.33	0.913	1.19	1.45	1.48	1.80	1.45
1830	1.34	1.68	1.08	1.41	1.49	1.72	1.83	1.95	2.31	2.08
1840	2.15	1.51	1.32	1.58	1.65	1.44	1.39	1.27	1.41	1.48
1850	1.25	0.567	1.49	1.47	1.76	1.17	0.92	1.35	1.81	1.07
1860	1.32	0.523	1.00	0.603	1.10	0.81	1.23	1.36	1.13	1.68
1870	1.08	0.863	1.09	1.08	1.06	1.22	1.18	1.08	1.37	0.937
1880	0.357	0.891	0.801	0.885	0.672	0.782	0.702	0.693	0.654	0.794
1890	0.57	0.705	0.734	0.439	0.581	0.720	0.594	0.796	0.970	0.351
1900	0.808	0.729	0.823	0.952	1.31	1.12	1.01	0.979	0.623	0.953
1910	0.917	0.668	0.842	0.95	1.08	1.18	0.994	0.734	0.67	0.81

Pike's Peak, 11,500 Feet (PPT), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1730	....	....	....	....	0.81	0.78	0.70	0.79	0.82	0.91
1740	0.98	1.12	1.16	1.00	1.18	1.00	1.09	1.20	0.82	1.15
1750	1.18	1.06	1.09	1.10	1.05	0.92	1.08	0.98	1.08	1.36
1760	1.10	0.99	1.22	1.14	1.03	1.27	1.09	1.12	0.81	0.86
1770	0.75	0.86	0.97	0.74	0.93	0.84	0.97	0.95	0.93	1.02
1780	1.18	1.01	0.82	1.07	1.21	1.06	1.13	1.09	0.90	0.96
1790	1.02	0.90	1.18	0.95	1.05	0.96	1.03	1.05	1.15	1.16
1800	0.92	0.94	1.05	0.94	0.80	0.68	0.78	0.94	0.80	0.87
1810	1.01	0.95	0.92	0.85	0.99 +	0.79 +	0.89 +	1.07	0.83	0.97
1820	0.90	0.98	0.90	0.84	0.94	0.98	0.94	1.07	0.86	0.83
1830	0.96	0.91	1.04	1.11	1.07	0.94	0.73	1.06	0.90	0.80
1840	0.90	1.00	0.73	0.95	1.03	0.92	0.85	0.85	1.05	1.02
1850	0.88	0.45	0.81	0.88	0.90	0.92	0.97	0.89 +	0.84	0.85
1860	0.90	0.85	1.01	1.03	1.04	0.82	1.07	1.29	1.09	0.51
1870	1.47	1.21	1.17	1.29	1.36	1.40	1.57	1.27	1.32	1.17
1880	1.00	1.23	1.00	1.12	1.15	1.17	1.35	1.22	1.34	1.27
1890	1.02	1.01	1.01	0.79	0.84	0.77	1.01	1.02	1.07	0.76
1900	0.94	0.91	0.87	0.95	0.83	0.80	0.73	1.01	0.69	0.87
1910	1.01	0.77	0.85	0.86	0.79 +	0.78	0.95	0.91	1.02	0.95
1920	0.77	....	....	....	....	....	....	....	....	....

Pike's Peak, 9,500 Feet (PPB), 3 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1690	....	....	....	1.35	1.07	1.38	1.14	0.96	1.18	1.24
1700	1.26	1.39	1.04	1.17	1.06	1.18	1.22	1.21	1.26	1.08
1710	1.30	1.13	1.25	0.84	1.13	0.89 +	1.00	1.18	1.26	1.10
1720	1.13	1.18	1.22	1.17	1.15	0.86	0.87	0.66	0.84	0.92
1730	0.88	1.02	1.02	0.93	1.07	0.57	0.72	0.86	0.92	1.21
1740	1.32	1.27	0.68	1.14	0.99	0.65	1.19	1.22	0.74	0.85
1750	0.76	0.80	0.72	0.75	0.23	0.75	0.62	0.89 +	0.79	0.89
1760	0.67	0.77	0.99−	0.24	0.87	0.71	0.97	0.98	1.12	1.23
1770	1.49 +	1.37	1.57	1.84	1.67	1.17	1.16	1.31	1.12	1.23
1780	1.11	0.85	0.94	1.03	0.99	1.30	0.85	0.88	1.05	0.32
1790	1.04	0.81	0.98	1.06	1.18	1.09	1.04	1.07	1.17	0.96
1800	1.20	0.80	1.27	0.82	0.96	0.75	0.71	0.86	0.69	0.74
1810	0.87	0.75	0.88	0.86	0.89	0.88	0.99 +	0.99 +	0.62	0.77
1820	0.70	0.53	0.70	0.66	0.66	1.07	0.84	0.83	0.90	0.75
1830	0.64	0.91	0.54	0.95	0.80	0.88	0.81	0.87	0.79	0.67
1840	0.54	0.49	0.49	0.60	0.49	0.43	0.81	0.68	0.65	0.45
1850	0.62	0.15	0.09	0.24	0.32	0.54	0.70	0.69	0.72	0.64
1860	0.82	0.62	1.08	0.85	1.23	0.96	1.69 +	1.08	0.93	1.60
1870	1.70	1.27	1.89 +	2.19	1.86	1.68	2.08	1.50	1.68	1.17
1880	0.72	1.14	1.17	1.53	1.49	1.59	1.52	1.59 +	1.97	2.13
1890	1.67	1.74	1.78	0.79	1.66	1.67	1.27	1.33	1.39 +	0.55
1900	1.48	1.58	1.36	1.56	1.07	1.37	1.18	1.12	0.67	1.21
1910	1.24	1.24	1.19	1.18	1.43	1.31	1.44	1.04	0.84	0.90
1920	0.72	....	....	....	....	....	....	....	....	....

Pike's Peak, High North Transect (HNT), 10 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1650	....	....	....	....	....	1.78	1.72	1.76	1.56	1.14
1660	1.85	1.32	1.42	1.32	0.99	1.13	0.76	0.99	0.55	1.02
1670	0.78	1.01	1.10	1.39	1.19	0.46	0.78	0.88	1.25	1.25
1680	1.82	1.35	0.41	0.49	0.62	0.54	0.88	0.93	1.07	1.30
1690	0.68	0.98	1.50	1.20	0.72	0.89	0.92	1.07	0.83	0.88
1700	0.87	1.37	1.37	1.24	1.13	0.98	1.33	0.87	1.02	0.73
1710	1.34	0.99	1.43	1.15	1.52	0.55	0.74	0.85	1.04	1.04
1720	1.36	1.07	1.09	1.00	1.11	1.34	1.58	0.79	1.14	0.98
1730	0.54	0.48	0.76	0.88	0.87	0.73	0.65	0.75	0.83	1.29
1740	1.09	0.78	0.36	0.81	0.81	0.48	1.11	1.17	0.48	0.62
1750	0.69	0.93	0.69	0.65	0.56	0.64	0.42	0.69−	0.49	0.71
1760	0.67	1.16	0.90	0.62	0.89−	0.85	1.24	0.91	1.60	1.33
1770	1.37	1.86	1.59 +	1.32	1.19 +	1.14	1.27	1.00	0.86	1.26+
1780	0.74 +	1.05	0.81	1.21	1.09 +	1.27	1.12	1.23	1.39+	0.57
1790	1.37	1.24	1.17	1.27	1.11	0.91	1.19 +	1.06	0.79+	0.99+
1800	1.31	0.79 +	1.37 +	1.39−	1.24	0.63	1.21	1.20	0.64−	0.88−
1810	1.25−	1.20	1.29	1.22	1.48	1.24	1.23	1.11	0.71	1.14+
1820	0.70	0.61	0.57	0.69	0.40	0.66	0.90 +	1.12	1.28	0.96
1830	0.80	1.13	0.65	1.07	1.05	1.63	1.29 +	1.27 +	1.58	1.52
1840	1.73	1.04	0.98 +	1.32	1.22	1.06	1.16−	0.91	0.93	0.91
1850	0.81−	0.29−	0.87	0.81	0.93 +	1.02	1.04	1.31	1.49	1.12
1860	1.56	0.85 +	1.10	0.64	1.16	0.69	1.02	1.04	0.98	1.41
1870	1.09	0.88 +	1.55 +	1.19	1.21	1.04−	1.41	1.02−	1.45	0.96−
1880	0.41	0.76−	0.97	1.07−	0.71	0.79 +	0.77	0.80	0.80	1.12
1890	0.93	0.79	0.76−	0.59 +	0.83	1.03	1.04	0.84 +	1.01	0.32 +
1900	0.82	0.78	0.84	0.97	1.05	0.83	0.92	1.05	0.65−	1.03
1910	0.93−	0.84	0.74	0.88−	0.92	0.99	0.89	0.71	0.86 +	0.79 +
1920	0.61	....	....	....	....	....	....	....	....	....

Pike's Peak, Low North Transect (LNT), 7 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1640	....	....	....	....	0.72	0.60	0.98	1.13	1.10	1.20
1650	0.68	1.18	1.15	1.13	0.33	1.33	1.38	1.33	1.17	0.56
1660	1.45	1.48	1.16	1.00	0.80	1.32	0.72	0.89	0.68	0.87
1670	0.77	1.18	1.17	1.22	1.02	0.57	0.41	0.48	0.79	0.70
1680	0.98	0.55	0.60	0.72	0.56	0.33	0.70	0.73	0.96	1.06
1690	0.54	0.81	1.15	0.98	0.61	0.87	0.80	1.05	0.81	0.81
1700	0.79 +	0.89 +	0.82	0.89	0.86	1.00	1.07	0.92	0.79	0.95
1710	1.27	0.89	0.98	0.96	1.12	0.67	0.83	0.68	0.65	1.17
1720	1.26	1.25	1.16	0.86	0.91	0.75	0.93	0.76	0.88	0.79
1730	0.56	0.39	0.56	0.59	0.51	0.56	0.49	0.51	0.55	0.83
1740	0.84	0.82	0.69	0.89	1.07	0.72	1.06	1.02	0.48	0.69 +
1750	0.71	0.82	0.89	1.10	0.89	1.03	0.85	1.29	0.56	0.69 +
1760	0.71	0.89	1.07	0.87	0.79	0.73	0.91	0.80	0.96	0.72
1770	0.82	1.00	1.25	1.20	1.07	0.84	1.01	0.90	0.85	0.90
1780	0.63	0.93	0.78	0.93	0.86	0.86	0.96	1.04	1.06	0.52
1790	1.02	0.98	1.09	0.98	0.86	0.88	0.91	0.81	0.57	0.86
1800	0.91	0.70	1.20	1.09	0.85	0.71	0.93	0.99	0.71	0.69
1810	0.87	0.75	0.80	0.85	1.05	0.88	1.02	1.14	0.78	0.78
1820	0.62	0.58	0.57	0.51	0.50	0.70	0.77	0.98	0.96	0.80
1830	0.64	0.91	0.50	0.73	0.71	0.68	0.81	0.90	1.02	0.86
1840	0.96	0.66	0.63	0.77	0.81	0.68	0.98	0.79 +	0.91	0.75
1850	0.86	0.24	0.87	0.96	1.05	1.16	0.90	1.08	1.24	1.09 +
1860	1.07	0.69	1.03	0.58	1.17	0.83	1.01	1.09	0.85	1.32
1870	1.05	0.85	1.18	1.19	0.96	0.93	1.09	0.92	1.13	0.71
1880	0.42	0.88	0.95	0.86	0.57	0.68	0.71	0.76	0.75	0.73
1890	0.61	0.78	0.85	0.64	0.78 +	0.82	0.72	0.92	1.07	0.39−
1900	0.90	0.77 +	0.88 +	1.00	0.98−	0.87	0.88	0.87 +	0.69	1.11
1910	0.97	0.79	0.91	1.04	1.25	1.21	1.09 +	0.91	0.75	0.95 +
1920	0.70	....	....	....	....	....	....	....	....	....

Pike's Peak, South Transect (ST), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1570	1.40	2.15	2.03	1.12	1.37	0.84	0.73	0.78	0.70	0.68
1580	0.61	1.17	0.93	1.00	1.09	1 07	1.20	0.65	0.63	0.76
1590	0.92	1.00	0.90	0.85	0.95	0.99	0.81	1.02	0.92	1.00
1600	1.18	0.96	0.91	0.92	1.35	0.76	0.73	0.93	0.73	0.95
1610	1.19	1.04	0.66	0.98	0.72	0.98	0.98	0.96	1.19	1.25
1620	0.91	0.80	0.85	1.12	1.19	1.09	1.10	0.82	0.95	1.09
1630	1.10	0.75	1.36	1.32	1.36	0.98	1.13	1.20	0.25	0.16
1640	0.36	0.29	0.42	0.20	0.36	0.41	0.55	0.45	0.66	0.77
1650	0.80	0.87	0.64	0.95	0.82	1.28	1.27	1.47	1.41	1.16
1660	1.44	1.53	1.44	1.35	1.08	1.15	0.97	0.42	0.32	0.60
1670	0.53	0.65	0.68	0.61	0.78	0.68	0.27 +	0.22	0.52	0.52
1680	0.46	0.51	0.70	0.62	0.74	0.83	0.96	1.01	1.14	1.17
1690	1.43	1.01	1.25	1.02	0.95	1.05	1.15	1.17	1.27	1.16
1700	1.48	1.12	1.19	1.23	1.42	1.58	1.28	1.33	1.18	1.33
1710	1.49	1.46	1.38	1.37	1.84	1.01	0.95	0.99 +	1.27	1.49 +
1720	1.45	1.12	0.78	0.62	0.89	1.00	1.01	0.81	0.95	1.27
1730	1.35	0.56	0.22	0.49	0.49	0.80	0.63	0.82	0.86	1.13
1740	1.05	1.06	0.91	1.12	0.98	0.77	0.82	0.95	0.88	0.73
1750	0.62	0.79	0.72	1.05	0.68	0.88	1.25	1.12	0.09	0.18
1760	0.55	0.68	0.74	0.70	0.73	0.66	0.77	1.14	0.84	0.97
1770	0.73	0.93	1.14	1.09	1.07	1.13	1.49	1.52	1.44	1.48
1780	1.01	1.26	0.99−	1.20	1.37	1.29	1.28−	1.21	1.54−	1.30
1790	1.46	1.30	1.39 +	1.65	1.57	1.60	1.71	1.25	0.99 +	1.17
1800	1.25	0.91	1.18	1.17	1.34	1.19	1.29 +	1.31	1.23	1.36−

Pike's Peak, South Transect (ST), 8 trees—Continued

A.D.	0	1	2	3	4	5	6	7	8	9
1810	1.29	1.35	1.59	1.34	1.65	1.42	1.71	1.70	1.38	1.14
1820	1.24	1.11	1.16	1.31	0.94−	1.19−	1.32	1.42	1.37	1.11
1830	0.94	1.17	0.74	0.88 +	0.88+	1.07+	0.97	1.04	1.16−	1.04
1840	1.09−	1.04	0.99 +	1.06	1.03	0.89+	1.08−	0.92	0.90	0.88
1850	0.98+	0.43−	0.95	0.96	1.15	1.07	0.81	0.95 +	1.12	0.78
1860	0.81	0.77	0.80	0.66	0.93	0.76	0.83	0.81	0.86 +	0.89+
1870	0.87−	0.74	0.89	0.98	0.81	0.92	0.99 +	0.88 +	1.11	0.76−
1880	0.73	0.76	0.80	0.59 +	0.56	0.50	0.68 +	0.76	0.71	0.73
1890	0.71	0.82	0.79	0.80	0.97	0.95	0.91	0.99 +	0.98	0.49+
1900	0.87	0.71	0.87	1.05	0.86	0.81	0.64	0.67	0.56	0.79+
1910	0.70	0.63	0.84 +	0.91	0.82	0.87	0.79 +	0.73	0.66 +	0.76+
1920	0.69 +	....	....	....	....	....	....	....	....	....

Pike's Peak, Brook, Douglas Fir and Pine (BDF), 6 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1780	....	....	0.64	0.61	0.58	0.88	0.87	1.18	1.36	0.73
1790	1.13	1.37	1.65	1.20	1.08	1.10	1.33	1.28	0.38	0.32
1800	0.60	0.59	0.90	1.01	1.28	0.87	1.26	1.33	1.21	1.03
1810	1.22	1.07	1.30	1.11	1.17	1.15	1.07	0.89	0.62	0.80
1820	0.82	0.73	0.71	0.67	0.60	0.83	1.20	1.32	1.45	1.33
1830	1.24 +	1.22	0.92	0.97	0.94	1.00	0.87	1.05	0.96	1.05
1840	1.13	0.67−	0.64	0.81	0.84	0.77	0.84	0.87 +	0.96	0.92 +
1850	0.90	0.58+	1.05	1.20	1.41	1.06	0.73	1.12 +	1.39 +	1.20
1860	1.15	0.75	1.02	0.62	0.90	0.59	0.97	1.00	0.78	1.13
1870	0.94	0.79	0.90	0.76	0.93	0.94	0.99	0.84	0.93	0.71
1880	0.35	0.79−	0.88	0.76	0.80	0.77	0.77	0.70	0.78	0.83
1890	0.75	0.76	0.71	0.58	0.76	0.94	0.80	0.94	0.95	0.46
1900	0.53−	0.65+	0.67	0.92	1.10	1.11	0.94	1.08	0.53	1.01
1910	1.03−	0.68−	0.81	1.03−	1.03−	1.37	1.25	0.73	0.64	1.00
1920	0.63−	....	....	....	....	....	....	....	....	....

Pike's Peak, Brook, Engelmann Spruce (BES), 4 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1770	....	....	....	....	....	1.11	0.78	1.07	1.09	1.15
1780	1.35	1.00	1.39	1.34	1.12	1.04	1.04	1.02	0.92	0.92
1790	1.04	1.08	1.43	1.07	1.11	1.13	1.12	1.00	0.98	0.74
1800	1.11	0.69 +	0.99	1.17	1.05	0.82	0.88 +	1.02	0.78	0.97
1810	0.87	0.97	1.00	0.86	1.00	1.09	1.07	1.19 +	1.00	1.10
1820	0.73	0.61	0.56	0.64	0.46	0.80	1.07	1.17	1.31	1.10
1830	0.95	1.11	0.74	0.72	0.81	1.00	1.19	1.09	1.15	1.11
1840	1.17 +	1.26	0.92	1.35	1.14	1.07	1.02	0.93	0.84	0.94
1850	0.87	0.64	0.74	0.82	0.97	0.99	0.66	0.61	0.81	0.38 +
1860	0.72	0.43	0.63	0.66	0.70	0.50	0.60	0.70	0.80	0.90
1870	1.09 +	1.10	1.10	1.00	1.03 +	1.07 +	1.09	1.09	1.42	1.40
1880	1.16	1.25	0.94	1.08	1.05	1.33	1.09	1.40	1.32 +	1.42
1890	1.06	0.84 +	0.79	0.53	0.71	0.87	0.83 +	1.01	1.12	0.82
1900	1.28	1.14	1.15	1.24	0.85	0.83	0.62	0.63	0.74 +	0.86
1910	0.76 +	0.93	0.64	1.15	1.16−	1.26	1.14	0.71	0.60	0.73
1920	0.57	....	....	....	....	....	....	....	....	....

Cloudcroft, New Mexico (CC), 3 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1730	....	....	....	....	....	....	1.21	1.27	1.27	0.90
1740	1.13	1.73	1.12	1.60	2.11	2.23	2.88	3.49	1.69	2.11
1750	1.88	2.62	0.87	2.10	2.08	2.42	2.45	3.02	3.39	2.81
1760	2.83	3.46	2.96	1.67	2.72	2.87	3.78	2.06	1.42	2.70
1770	2.10	2.48	1.92	2.13	2.21	1.96	2.74	2.34	1.70	2.47
1780	1.82	1.92	1.05	1.48	2.26	1.48	1.80	2.37	2.03	1.33
1790	2.51	2.29	2.87	3.11	2.28	1.58	2.71	1.97	1.34	2.40
1800	2.49	1.91	2.18	2.42	2.15	2.62	2.70	1.83	2.09	1.78
1810	1.98	2.00	1.33	2.01	2.24	2.86	2.26	1.42	1.88	0.95
1820	0.84	0.66	1.00	1.39	1.49	1.30	1.44	1.96	1.13	1.96
1830	1.17	0.91	1.30	1.35	1.74	1.22	0.95	0.54	0.61	0.90
1840	1.01	0.70	0.54	0.58	1.05	0.91	1.14	0.45	0.85	0.71
1850	0.40	0.38	1.05	1.08	1.13	0.68	1.37	0.92	1.07	0.32
1860	0.66	1.38	0.45	1.09	0.85	0.96	1.28	1.12	1.89	2.14
1870	1.12	1.52	1.60	1.24	1.18	1.38	2.03	1.31	1.29	1.13
1880	1.15	1.28	1.88	1.66	2.05	2.13	1.58	2.04	1.39	1.51
1890	1.66	1.32	0.75	0.56	0.81	1.06	0.92	1.20	1.96	1.08
1900	1.38	1.19	0.87	1.41	0.51	1.11	0.87	1.48	0.99	0.73
1910	0.72	1.25	1.01	1.20	1.27	0.70	1.17	1.38	1.36	1.32
1920	1.28	....	....	....	....	....	....	....	....	....

Santa Fe, New Mexico (SF), 6 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1740	....	....	....	....	....	....	....	....	....	4.94
1750	3.12	3.48	3.72	3.20	5.18	5.56	2.72	3.52	2.80	3.66
1760	2.80	5.52	4.70	2.88	5.00	3.40	4.94	4.32	2.64	2.96
1770	1.98	3.28	2.38	1.48	2.08	2.08	2.12	2.16	2.40	1.76
1780	2.24	2.20	2.10	2.20	1.70	2.06	2.00	1.94	1.60	1.28
1790	1.24	2.62	2.36	3.12	2.42	2.50	2.64	1.96	2.30	2.30
1800	2.56	1.90	2.30	2.02	2.50	1.64	1.38	1.80	2.32	1.50
1810	1.98	1.42	1.32	2.00	1.70	2.60	2.74	1.92	1.46	1.94
1820	2.32	2.02	1.16	1.64	1.64	2.28	2.24	2.30	2.42	2.24
1830	2.20	2.06	2.36	2.10	2.82	2.58	2.20	2.22	2.78	2.76
1840	2.54	2.08	0.90	1.32	2.12	1.58	1.92	1.20	1.14	1.74
1950	1.58	1.90	2.56	1.92	2.64	2.12	2.12	2.02	2.34	1.64
1860	1.56	1.78	1.76	1.80	1.42	1.94	2.68	2.50	3.02	2.96
1870	2.22	2.12	2.38	1.34	1.90	2.62	2.06	2.34	2.18	1.86
1880	1.02	1.22	1.96	1.82	2.50	2.14	2.40	2.62	1.98	1.68
1890	1.28	1.60	1.80	1.38	1.84	2.00	1.24	2.48	1.96	1.24
1900	1.92	2.08	1.42	2.12	0.72	2.10	2.02	2.84	2.64	1.64
1910	1.62	1.74	1.84	1.88	2.10	1.54	2.06	1.10	1.24	1.76
1920	1.64	2.28	....	....	....	....	....	....	....	....

Modern H, 17, 22, 23, 24, 25, 26 (BMH), 6 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1580	....	....	....	....	....	....	....	....	0.71	1.02
1590	0.94	1.36	1.06	1.12	1.48	2.10	1.97	2.04	2.08	2.99
1600	1.78	2.14	2.64	2.87	3.41	3.36	3.14	2.77	3.13	2.77
1610	3.48	3.56	2.70	2.59	2.67	2.67	2.48	2.30	2.39	2.68
1620	2.26	2.81	1.86	1.39	1.66	2.30	1.94	2.72	2.28	2.73
1630	1.84	1.13	1.04	1.82	2.01	2.13	2.26	2.07	1.35	1.87
1640	2.52	1.90	1.58	1.60	2.87	2.13	2.54	2.05	1.64	1.86

Modern H, 17, 22, 23, 24, 25, 26 (BMH), 6 trees—Continued

A.D.	0	1	2	3	4	5	6	7	8	9
1650	2.32	2.14	2.25	2.38	1.70	2.57	2.30	1.80	1.47	1.63
1660	1.81	2.22	1.97	1.72	1.34	1.61	1.18	1.18	1.03	1.34
1670	1.18	1.62	2.77	1.84	1.60	1.72	0.95	1.38	1.50	1.74
1680	2.06	2.05	1.38	2.08	1.41	0.18	1.31	1.92	2.36	2.18
1690	1.65	1.42	1.95	1.44	1.35	1.41	1.02	1.38	1.34	1.91
1700	1.50	2.18	1.50	1.12	1.16	1.92	1.72	0.99	1.32	1.72
1710	1.48	1.73	1.22	1.47	1.30	1.47	1.32	1.33	1.48	1.42
1720	1.79	1.59	1.54	1.78	1.60	2.10	1.87	1.31	1.45	0.75
1730	0.74	0.81	0.86	0.79	1.06	0.28	0.54	0.59	0.82	0.78
1740	0.72	0.79	0.97	1.21	1.06	1.50	1.67	1.78	0.42	1.36
1750	1.44	1.04	0.91	1.15	1.23	0.59	0.62	0.67	0.76	1.12
1760	1.01	1.27	1.48	1.48	1.68	1.24	1.63	1.64	1.40	0.97
1770	1.30	1.57	1.58	0.61	1.12	0.80	0.79	0.79	0.71	0.72
1780	0.64	0.67	0.74	0.81	1.08	0.56	0.84	0.97	0.60	0.80
1790	0.81	1.13	1.05	1.25	1.24	1.10	0.91	0.91	1.02	1.12
1800	1.35	1.06	1.28	1.05	0.88	0.91	0.77	0.77	0.66	0.75
1810	0.87	0.90	0.81	0.43	0.65	1.03	1.07	0.72	0.16	0.45
1820	0.36	0.48	0.26	0.25	0.50	0.51	0.61	0.48	0.85	0.67
1830	1.02	0.87	0.81	0.90	0.70	0.84	0.82	0.82	0.87	0.92
1840	0.88	1.00	0.71	0.85	0.76	0.76	0.69	0.07	0.66	0.87
1850	0.71	0.30	0.87	0.95	0.65	0.66	0.65	0.89	0.89	0.54
1860	0.80	0.16	0.85	0.72	0.33	0.72	0.89	0.91	1.23	1.19
1870	0.73	0.32	0.62	0.72	0.62	0.92	0.72	0.85	0.92	0.45
1880	0.68	0.76	0.57	0.65	0.76	0.93	0.68	0.87	0.84	0.72
1890	0.84	0.94	0.78	0.59	0.60	0.59	0.37	0.74	0.70	0.39
1900	0.28	0.42	0.12	0.75	0.37	0.78	0.70	1.04	1.12	1.02
1910	1.16	1.14	0.82	0.82	1.06	0.94	1.05	0.82	0.81	0.72

Modern H, 27, 28 (BML), 2 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1700	1.28	1.25	1.76	1.28	0.96	1.23	1.59	0.97	1.15	1.21
1710	1.70	1.99	1.72	1.65	1.34	1.50	1.57	1.47	1.84	2.55
1720	2.96	3.07	3.26	2.78	2.74	4.00	4.06	2.88	3.04	1.75
1730	3.75	3.26	3.20	3.55	3.39	1.26	1.99	1.94	2.67	2.02
1740	1.94	1.82	2.49	2.61	2.94	3.43	4.32	3.48	1.56	3.11
1750	2.44	1.98	1.99	1.74	2.37	1.19	1.35	1.37	1.61	2.27
1760	2.13	2.00	2.83	2.17	2.47	1.72	2.57	2.66	2.75	1.77
1770	1.84	2.79	2.85	1.28	1.82	1.50	1.37	1.11	1.37	1.13
1780	1.13	1.36	1.38	1.75	2.02	1.05	1.58	2.21	1.12	1.11
1790	1.48	1.69	1.59	2.28	1.88	1.65	1.08	1.31	1.46	1.67
1800	1.84	1.24	2.03	1.43	1.65	1.43	1.31	1.35	1.57	1.03
1810	1.33	1.66	1.41	1.07	1.49	1.85	1.72	1.52	0.64	0.94
1820	0.82	0.71	0.27	0.31	0.62	0.68	1.02	0.98	1.46	1.05
1830	1.70	1.08	1.57	1.31	1.31	1.41	1.37	1.58	1.56	1.53
1840	1.33	1.67	1.25	1.32	1.09	1.17	0.83	0.35	0.70	1.04
1850	0.75	0.39	1.07	1.12	0.91	0.94	1.05	1.22	0.92	0.66
1860	1.20	0.44	1.14	0.80	0.50	0.96	1.28	1.09	1.22	1.39
1870	1.10	0.40	0.67	0.74	0.66	1.24	0.57	1.08	1.17	0.68
1880	0.80	1.17	0.88	0.66	1.28	1.39	0.88	1.36	1.40	1.13
1890	1.43	1.29	1.15	0.90	0.81	0.71	0.51	0.98	0.84	0.41
1900	0.33	0.48	0.02	0.81	0.26	0.75	0.84	1.51	1.45	1.37
1910	1.37	1.64	1.33	1.28	1.61	1.47	1.70	0.88	....	....

Modern H, 39, 40, 41, 42 (AE), 4 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1660	....	....	2.30	1.50	1.20	2.25	0.72	0.82	0.72	0.45
1670	0.79	1.13	1.21	1.40	1.70	1.43	0.83	1.24	1.72	1.06
1680	1.81	1.72	1.31	1.67	0.85	0.17	1.80	1.68	1.23	1.87
1690	2.55	1.60	2.55	2.63	1.61	1.40	0.90	1.30	1.97	2.42
1700	1.79	2.37	1.20	1.38	0.98	1.64	2.07	1.07	1.54	1.41
1710	2.49	2.01	1.46	1.04	0.76	1.22	1.00	1.24	1.75	1.70
1720	2.30	1.78	1.30	1.67	0.97	1.30	1.90	2.04	1.66	0.29
1730	0.95	1.16	1.51	1.21	1.45	0.36	1.04	0.77	0.96	1.00
1740	0.86	0.90	0.77	1.16	0.80	1.08	1.45	1.98	0.61	1.82
1750	1.26	1.06	0.93	0.72	1.21	0.82	0.70	0.69	0.71	0.81
1760	0.73	0.73	0.96	0.93	0.99	0.66	1.50	0.85	1.26	1.10
1770	1.44	1.56	1.18	0.34	0.84	0.95	0.55	0.53	0.66	0.57
1780	0.52	0.68	0.58	0.77	0.75	0.68	0.70	0.97	0.52	0.40
1790	0.47	0.63	0.76	0.91	0.48	0.66	0.64	0.44	0.52	0.59
1800	0.62	0.31	0.86	0.60	0.62	0.43	0.24	0.66	0.59	0.62
1810	0.42	0.75	0.80	0.54	0.63	1.09	1.44	1.29	0.37	0.40
1820	0.31	1.00	0.43	0.41	0.35	0.58	0.56	0.39	0.87	0.68
1830	0.90	0.86	1.25	1.19	0.86	0.93	0.64	0.70	0.83	1.11
1840	1.12	1.01	0.84	0.76	0.54	0.59	0.69	0.04	0.76	0.66
1850	0.76	0.25	0.77	0.92	0.68	0.66	0.67	0.48	0.65	0.45
1860	0.60	0.02	0.69	0.39	0.10	0.38	0.37	0.55	0.65	0.85
1870	0.40	0.00	0.42	0.25	0.43	0.44	0.43	0.10	0.46	0.26
1880	0.26	0.29	0.27	0.25	0.38	0.21	0.39	0.52	0.59	0.44
1890	0.69	0.69	0.73	0.74	0.54	0.27	0.24	0.35	0.16	0.46
1900	0.37	1.12	0.25	0.26	0.32	0.38	0.32	0.44	0.38	0.38
1910	0.37	0.53	0.66	0.35	0.80	0.85	0.99	0.92	0.52	0.84

COAST ZONE

Boise, Idaho (BI), 10 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1650	....	....	1.70	0.65	1.50	1.65	2.05	1.05	1.70	2.05
1660	1.70	1.75	1.30	1.50	1.30	1.00	1.60	1.40	0.90	1.50
1670	1.80	1.75	1.15	1.60	0.90	1.15	0.90	0.80	0.80	1.25
1680	0.75	1.25	1.10	1.20	1.20	1.05	1.00	1.40	1.40	1.25
1690	2.00	1.75	2.15	2.45	3.55	2.35	1.95	2.45	2.15	2.15
1700	2.20	2.05	3.15	3.20	1.85	2.30	2.90	2.40	1.75	1.60
1710	2.05	1.85	1.95	1.75	1.10	0.90	1.35	0.95	1.10	1.00
1720	1.50	0.50	0.60	0.95	0.80	0.75	0.80	1.00	0.75	0.50
1730	0.50	0.85	1.20	1.05	1.00	1.20	1.00	1.45	1.60	1.00
1740	1.00	1.35	0.90	1.35	1.05	1.35	1.75	1.50	1.45	1.45
1750	1.95	2.20	2.35	1.60	1.64	2.28	1.80	1.58	2.21	2.09
1760	1.98	2.91	2.79	2.33	2.06	2.45	2.51	2.88	2.51	2.05
1770	1.98	1.98	2.28	1.12	0.81	1.28	1.65	1.81	1.32	1.42
1780	1.80	1.48	1.74	1.38	1.14	1.62	1.63	1.29	1.57	1.55
1790	1.67	1.99	2.19	1.98	1.56	1.27	1.37	1.15	0.93	1.36
1800	1.53	1.57	1.49	1.44	1.45	1.61	1.59	0.97	1.11	1.15
1810	0.60	0.70	1.02	0.98	1.18	1.10	1.12	1.00	1.15	1.15
1820	1.15	1.23	1.11	1.20	1.09	1.07	0.97	1.08	1.25	1.18
1830	1.06	0.83	1.36	1.01	0.87	1.00	1.02	1.01	1.00	0.91
1840	0.77	0.88	0.92	0.79	0.74	0.89	0.85	0.79	0.72	0.70
1850	0.82	0.79	0.71	0.68	0.99	0.83	0.67	0.93	0.88	0.64
1860	0.94	1.06	0.90	0.76	0.72	0.68	0.90	0.78	0.92	0.91
1870	0.70	0.71	0.88	0.91	0.84	0.91	0.93	0.94	0.94	0.96
1880	0.73	0.82	0.70	0.60	0.80	1.07	0.71	0.85	0.76	0.48
1890	0.45	0.69	0.78	0.53	0.63	0.72	0.64	0.36	0.59	0.62
1900	0.83	0.87	0.85	0.85	0.76	0.75	0.59	0.68	0.86	0.87
1910	0.86	0.87	0.78	0.79	0.63	0.58	0.52	0.42	0.74	0.93
1920	0.64	0.79	0.75	....	....	....	....	....	....	....

Boise, Idaho, 3 trees selected

A.D.	0	1	2	3	4	5	6	7	8	9
1650	....	....	1.70	0.65	1.50	1.65	2.05	1.05	1.70	2.05
1660	1.70	1.75	1.30	1.50	1.30	1.00	1.60	1.40	0.90	1.50
1670	1.80	1.75	1.15	1.60	0.90	1.15	0.90	0.80	0.80	1.25
1680	0.75	1.25	1.10	1.20	1.20	1.05	1.00	1.40	1.40	1.25
1690	2.00	1.75	2.15	2.45	3.55	2.35	1.95	2.45	2.15	2.15
1700	2.20	2.05	3.15	3.20	1.85	2.30	2.90	2.40	1.75	1.60
1710	2.05	1.85	1.95	1.75	1.10	0.90	1.35	0.95	1.10	1.00
1720	1.50	0.50	0.60	0.95	0.80	0.75	0.80	1.00	0.75	0.50
1730	0.50	0.85	1.20	1.05	1.00	1.20	1.00	1.45	1.60	1.00
1740	1.00	1.35	0.90	1.35	1.05	1.35	1.75	1.50	1.45	1.45
1750	1.95	2.20	2.35	1.60	1.64	2.28	1.80	1.58	2.22	2.09
1760	1.98	2.91	2.79	2.33	2.06	2.45	2.51	2.82	2.51	2.05
1770	1.98	1.98	2.28	2.15	0.84	1.32	1.71	1.88	1.37	1.49
1780	1.89	1.50	1.80	1.63	1.12	1.88	1.80	1.39	1.53	1.65
1790	1.23	2.45	2.45	2.36	1.89	1.49	1.72	1.45	1.15	1.63
1800	1.74	1.55	1.63	1.72	2.01	1.96	2.05	1.20	0.93	0.83
1810	0.25	0.33	0.59	0.68	1.10	1.18	1.26	1.23	1.41	1.41
1820	1.28	1.45	1.78	1.33	1.36	1.42	1.56	1.45	1.70	1.80
1830	1.42	0.90	1.82	1.78	1.12	1.10	1.20	1.25	1.48	1.18
1840	0.92	1.25	1.25	0.95	0.75	0.78	0.78	0.35	0.48	0.58
1850	0.65	0.68	0.42	0.82	1.08	0.81	0.75	0.93	0.82	0.63
1860	0.88	0.95	0.94	0.92	0.81	0.77	1.03	1.03	1.11	1.09
1870	0.81	0.78	0.82	0.91	1.15	1.14	1.03	1.16	1.17	1.12
1880	1.05	0.93	0.73	0.60	0.73	1.07	0.87	0.92	0.91	0.42
1890	0.41	0.65	0.72	0.40	0.53	0.55	0.39	0.16	0.45	0.40
1900	0.36	0.49	0.62	0.41	0.63	0.61	0.49	0.55	0.85	0.80
1910	0.68	0.85	0.46	0.62	0.58	0.59	0.50	0.31	0.66	0.90
1920	0.65	0.41	0.55	....	....	....	....	....	....	....

Baker, Oregon (BO), 7 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1660	1.60	1.65	0.55	1.10	1.25	1.10	2.00	2.40	2.00	2.10
1670	2.85	3.35	2.70	2.20	2.20	1.90	1.45	1.25	1.80	1.65
1680	0.90	1.00	1.00	0.90	1.25	1.35	1.60	1.25	1.35	1.60
1690	1.35	1.45	1.45	1.00	1.50	1.20	1.20	1.45	1.05	0.80
1700	0.75	0.60	0.80	1.00	0.95	1.30	1.80	1.65	1.50	1.70
1710	2.80	3.20	2.95	2.40	1.75	2.70	2.40	1.50	1.65	1.00
1720	1.25	0.90	1.10	1.10	1.10	1.65	2.10	2.20	1.45	1.55
1730	1.90	1.60	1.75	1.75	1.25	1.70	1.50	2.10	1.60	1.20
1740	1.25	1.35	1.05	1.05	1.25	1.45	1.25	1.10	1.10	1.30
1750	1.35	1.20	1.30	0.85	0.85	0.80	0.50	0.65	0.65	0.45
1760	1.15	1.20	0.80	0.75	0.74	0.64	0.90	0.82	0.78	0.78
1770	0.88	0.97	1.02	0.98	1.06	0.90	0.75	0.64	0.85	0.95
1780	1.10	0.84	0.86	0.78	0.66	0.47	0.79	0.72	0.86	1.04
1790	1.13	1.74	1.92	1.55	1.70	1.50	1.79	1.02	1.32	1.29
1800	1.18	1.16	1.14	1.14	0.91	1.03	0.90	0.82	0.89	1.11
1810	1.04	1.04	1.64	1.42	1.66	1.23	1.24	1.09	1.22	1.64
1820	1.17	1.23	1.65	0.87	1.58	1.84	1.53	0.89	1.08	0.93
1830	0.87	1.18	1.15	1.05	0.89	0.89	1.21	1.38	1.67	1.69
1840	1.14	1.11	0.83	0.70	0.77	1.12	0.94	0.59	0.84	0.78
1850	0.57	0.81	0.77	0.87	0.88	1.23	0.97	1.16	1.23	1.00
1860	1.00	1.19	1.06	1.12	1.18	1.29	1.87	1.39	1.66	1.32
1870	1.28	1.20	1.26	1.52	1.29	1.35	1.79	2.03	1.89	1.71
1880	1.39	1.72	1.29	0.98	1.08	1.44	1.05	1.05	1.18	0.87
1890	0.75	1.02	0.85	0.72	1.16	0.95	1.01	1.16	1.21	0.80
1900	1.23	1.09	0.99 +	1.06	1.17	1.02	0.91	1.10	0.93	0.94
1910	0.76	0.69	0.81	1.05	0.78	0.82	0.95	0.60	0.65	0.71
1920	0.61	0.76	0.32	0.60	0.52	....	....	....	....	....

The Dalles, Oregon (DL), 3 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1760	....	....	....	....	....	3.00	3.30	3.50	1.94	2.72
1770	1.55	1.93	2.23	1.72	1.68	1.57	0.87	0.92	0.93	1.10
1780	0.75	0.98	1.30	1.18	0.99	0.90	1.64	1.01	0.82	0.88
1790	0.97	0.81	1.20	1.18	0.84	0.60	0.49	0.58	1.10	1.18
1800	1.11	1.12	1.25	0.93	0.79	1.10	1.25	1.26	1.68	1.43
1810	1.39	1.39	1.56	1.81	1.45	1.35	1.18	1.15	0.80	1.28
1820	1.21	1.05	0.93	0.81	0.82	0.84	0.99	1.25	0.88	1.15
1830	1.25	1.08	1.00	1.35	1.12	1.21	1.00	0.88	0.99	0.67
1840	0.68	0.44	0.66	0.92	0.74	1.02	0.98	0.54	0.48	0.34
1850	0.63	0.42	0.65	0.69	0.94	0.88	0.96	1.02	1.05	1.05
1860	1.21	1.08	1.09	1.17	1.63	1.06	1.23	1.12	1.07	1.07
1870	1.30	1.23	1.39	1.09	1.18	0.74	1.24	1.11	1.03	1.01
1880	1.16	1.00	1.34	1.12	1.23	1.16	1.19	1.01	0.77	0.68
1890	0.55	0.37	0.38	0.39	0.54	0.73	0.95	1.38	1.21	1.03
1900	1.14	1.13	0.85	1.09	1.13	0.79	0.85	0.82	1.14	0.79
1910	0.66	0.70	0.83	0.97	0.85	0.91	0.89	0.92	0.74	0.70
1920	0.68	1.12	0.89	0.68	1.05	....	....	....	....	....

Oregon Coast (OC)

(See Volume I, Appendix, page 117)

Klamath Falls, Oregon (KF), 12 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1790	....	....	1.01	1.17	0.83	0.69	0.75	1.16	1.25	1.74
1800	1.02	1.05	1.32	1.23	1.12	1.23	1.44	1.18	1.15	1.35
1810	1.14	1.18	0.94	1.93	0.94	0.86	0.91	0.96	1.16	1.15
1820	0.93	0.95	0.81	0.83	0.56	0.92	0.91	0.86	0.94	0.61
1830	1.05	1.08	1.47	0.87	0.91	1.47	1.64	1.51	1.43	0.48
1840	1.08	0.57	0.73	0.63	0.35	0.76	0.50	0.69	0.81	0.72
1850	0.91	0.97	0.84	1.21	0.94	1.00	0.85	0.94	0.79	0.69
1860	1.10	1.35	0.99	0.99	0.98	0.84	1.01	1.03	1.09	0.42
1870	0.72	0.54	0.66	0.85	0.91	0.80	1.08	1.05	1.15	0.98
1880	0.85	1.12	0.81	0.93	1.13	1.04	0.96	1.04	0.99	0.32
1890	0.69	0.79	0.85	1.14	1.56	1.12	1.12	1.21	0.35	0.79
1900	0.92	1.04	0.99	1.20	1.19	0.92	0.95	1.12	1.00	1.19
1910	1.19	0.94	1.08	1.33	1.23	0.77	1.18	0.86	0.50	0.76
1920	0.31	0.61	0.51	0.75	....	....	....	....	....	....

Meadow Valley Pines, Plumas County, California (CP), 9 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1550	....	2.13	1.95	1.80	1.98	2.91	2.37	1.80	1.50	1.17
1560	1.26	1.47	1.62	1.77	1.68	1.92	1.11	0.93	1.26	1.20
1570	0.90	1.59	1.32	1.26	1.53	1.68	2.19	1.29	1.38	0.93
1580	1.02	1.05	1.23	1.35	1.17	1.23	1.26	1.23	0.75	0.36
1590	0.90	1.05	0.90	0.42	0.24	0.51	0.75	0.90	0.90	0.87
1600	1.17	1.11	1.50	0.99	0.75	1.20	1.23	1.20	1.05	1.08
1610	1.80	1.44	0.96	1.50	1.53	1.20	1.50	1.83	1.44	1.80
1620	1.95	1.35	1.53	2.40	1.80	1.74	1.50	2.76	1.80	2.31
1630	2.19	1.80	2.01	2.46	3.66	3.51	3.54	4.50	3.03	2.64
1640	2.88	3.60	3.09	3.84	4.02	2.91	3.84	3.39	2.55	3.21
1650	3.24	3.69	2.70	2.67	2.76	3.66	3.42	2.94	3.12	3.63
1660	2.43	3.30	3.30	2.40	3.30	2.79	3.15	3.51	2.94	3.27

Meadow Valley Pines (CP), 9 trees—Continued

A.D.	0	1	2	3	4	5	6	7	8	9
1670	2.88	2.67	3.00	3.72	3.42	3.48	2.88	2.97	3.09	3.24
1680	3.12	3.75	3.39	2.82	3.27	3.57	3.39	2.94	3.18	2.16
1690	2.52	3.48	3.18	2.58	3.78	2.97	2.79	2.79	2.73	3.12
1700	3.12	2.16	2.64	2.88	2.97	2.97	2.73	2.97	3.03	2.67
1710	3.21	2.22	2.67	2.49	2.85	3.30	3.75	3.54	3.21	2.82
1720	3.24	2.85	3.18	3.03	2.46	2.61	3.21	2.85	2.61	2.82
1730	3.12	3.03	2.88	2.49	2.67	2.82	3.12	2.61	3.21	2.97
1740	2.58	2.61	2.61	3.06	2.70	2.64	2.43	2.76	2.37	2.85
1750	2.82	2.85	2.52	2.64	3.03	3.15	2.49	2.58	2.76	3.12
1760	2.37	2.97	2.55	2.10	2.25	2.64	2.49	2.37	2.46	2.13
1770	2.52	2.28	2.46	2.70	2.85	2.97	2.49	2.07	2.67	2.64
1780	3.30	2.73	2.70	2.97	2.73	2.97	3.18	2.37	2.70	2.43
1790	2.52	2.91	3.42	3.33	3.06	2.91	2.31	2.70	3.63	3.39
1800	3.66	3.33	2.91	3.30	3.78	3.63	3.57	3.72	4.11	4.56
1810	4.74	4.44	4.92	3.99	4.17	3.30	3.51	3.21	3.57	3.57
1820	3.33	2.49	2.58	1.68	1.89	2.37	2.76	2.70	2.43	2.91
1830	1.95	2.13	2.91	2.46	2.25	2.46	2.40	2.82	2.37	2.31
1840	2.85	3.09	2.70	3.06	2.82	3.63	3.51	2.94	2.25	1.83
1850	2.19	2.58	2.67	2.43	2.43	3.00	2.58	2.61	2.19	2.16
1860	2.70	2.61	2.10	2.34	2.19	2.25	2.49	3.18	2.82	3.18
1870	3.39	3.36	3.48	3.27	2.70	2.79	2.34	2.73	2.43	2.58
1880	2.01	2.70	1.71	1.68	1.95	2.31	1.59	1.79	1.83	1.65
1890	1.59	1.89	1.89	2.10	2.31	1.83	2.04	1.98	1.77	1.92
1900	2.67	2.10	2.13	2.16	2.01	2.07	2.07	2.19	2.16	1.98
1910	1.59	1.77	2.28	2.22	2.07	1.77	1.74	1.62	1.65	1.68
1920	1.59	1.92	....	....	....	....	....	....	....	....

Calaveras Pines (CVP), 14 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1620	....	1.60	1.70	1.40	1.30	1.15	1.95	1.35	1.40	1.65
1630	1.55	0.90	1.15	1.40	1.45	1.55	1.90	2.45	2.10	1.45
1640	1.20	1.40	1.45	1.75	1.80	1.80	1.80	2.20	1.90	1.45
1650	1.95	1.50	1.50	0.60	1.65	0.70	1.60	1.05	0.90	1.15
1660	1.85	1.50	1.70	2.05	1.15	1.10	1.75	1.80	0.95	1.88
1670	1.93	1.83	1.65	2.15	1.70	1.83	1.58	1.88	1.88	1.65
1680	1.60	2.90	2.08	1.35	2.00	2.75	1.95	1.65	2.03	1.40
1690	1.48	1.95	1.35	1.53	2.25	2.20	1.88	1.55	1.50	2.52
1700	1.95	1.20	1.32	2.41	2.00	2.90	2.48	2.00	2.12	2.58
1710	2.81	1.89	2.78	2.31	2.57	2.14	2.05	2.04	1.70	1.59
1720	1.85	1.85	1.67	2.32	2.11	1.68	2.30	2.10	1.56	1.12
1730	1.62	1.65	1.56	1.36	1.42	1.20	1.78	1.28	1.56	1.69
1740	1.59	2.21	1.71	1.26	1.46	1.34	1.55	1.63	1.31	1.86
1750	1.97	1.91	1.75	1.74	1.26	1.74	1.35	1.15	1.83	1.88
1760	1.60	2.14	1.73	1.14	1.32	1.42	1.84	1.31	1.77	1.54
1770	2.24	1.69	2.14	2.06	1.81	1.77	1.46	1.05	1.14	1.18
1780	1.16	0.95	1.24	1.12	1.30	1.69	1.39	1.03	1.53	1.26
1790	1.24	1.59	2.15	1.74	1.41	1.33	1.33	1.35	1.28	1.30
1800	1.32	0.92	1.17	1.18	1.29	1.40	1.28	1.26	1.43	1.44
1810	1.48	1.54	1.60	1.89	2.02	1.74	1.87	1.41	1.66	1.48
1820	1.52	1.47	1.44	1.29	1.22	1.61	1.62	1.61	1.72	1.76
1830	1.84	1.96	2.46	1.99	1.23	1.49	1.53	1.34	1.64	1.54
1840	1.95	1.59	1.82	1.48	1.32	2.16	1.65	1.73	1.57	1.20
1850	1.36	1.49	1.45	1.82	1.67	2.18	1.67	1.48	1.45	1.17
1860	2.39	1.87	1.45	1.40	1.79	1.26	1.42	1.28	1.79	1.98
1870	2.86	2.24	2.36	2.60	1.59	2.33	1.90	2.01	2.26	2.22
1880	1.78	2.08	1.66	1.75	2.24	2.32	1.67	1.50	1.47	1.62
1890	1.48	1.70	1.82	1.97	2.18	1.91	1.81	1.71	1.69	1.74
1900	2.28	1.65	1.60	1.77	1.48	1.70	1.61	1.62	1.37	1.02
1910	1.22	1.03	1.22	1.42	1.50	1.26	1.06	0.84	0.80	1.03
1920	1.07	1.12	0.95	1.18	0.57	....	....	....	....	....

Big Creek, California (BC), 5 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1700	....	....	....	0.80	0.60	1.08	0.58	0.70	0.73	0.60
1710	1.12	1.05	1.12	1.00	1.18	0.93	1.18	1.38	2.40	2.10
1720	2.22	1.53	1.66	1.89	1.56	1.85	1.97	1.82	1.45	0.96
1730	1.84	2.11	2.15	1.59	1.94	1.71	1.95	1.89	3.18	2.60
1740	3.56	3.05	3.22	2.94	3.19	3.42	4.08	3.62	3.24	2.84
1750	2.86	2.81	2.43	2.18	2.48	2.11	1.81	1.90	1.86	2.41
1760	2.62	2.72	2.06	2.27	1.89	2.10	2.68	1.82	2.26	2.87
1770	2.62	3.28	2.36	3.13	2.70	1.88	1.63	1.13	1.71	1.70
1780	1.96	2.06	1.70	1.32	2.57	2.55	1.84	1.93	1.52	2.39
1790	2.71	2.12	2.29	2.22	1.59	1.13	1.68	2.05	1.76	2.17
1800	1.98	2.38	2.36	2.20	2.24	1.97	2.18	2.62	2.16	2.04
1810	2.95	2.44	1.77	2.47	2.32	2.53	2.45	2.06	1.92	1.92
1820	1.79	1.66	1.63	1.77	1.58	2.16	1.89	1.78	2.02	1.23
1830	2.28	2.00	1.75	1.91	1.65	1.78	2.25	1.42	1.64	1.68
1840	1.84	1.26	1.45	1.22	0.87	1.67	1.22	1.14	1.17	1.06
1850	1.39	1.41	1.44	2.00	1.61	1.59	1.78	1.52	1.32	1.54
1860	2.03	1.56	1.28	1.13	0.78	1.35	1.29	1.24	1.70	1.55
1870	1.54	1.64	2.52	1.62	1.46	1.83	1.46	1.26	1.87	1.19
1880	1.08	1.17	0.83	0.80	1.53	1.14	0.98	1.00	1.06	0.99
1890	1.38	1.27	1.04	1.34	1.36	1.55	1.43	1.70	1.15	1.23
1900	1.28	1.52	0.93	1.11	0.99	1.37	1.21	1.42	1.14	1.28
1910	1.46	0.93	0.72	0.93	1.38	1.03	1.04	0.98	1.03	1.09

Springville Pines (EP), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1720	0.70	0.62	0.90	1.18	0.65	0.72	0.78	0.90	0.65	0.51
1730	0.68	0.50	0.70	0.85	0.62	0.65	0.70	0.55	1.00	0.68
1740	0.62	0.92	0.82	0.62	0.78	1.05	0.70	0.92	0.92	0.85
1750	1.12	0.85	0.85	1.00	0.65	0.51	0.65	0.72	1.08	0.85
1760	0.78	1.25	0.92	1.15	1.05	0.92	1.33	1.22	1.40	0.73
1770	0.92	1.12	1.21	1.52	1.52	1.50	1.29	0.60	0.78	0.92
1780	1.01	0.73	0.96	0.51	0.62	0.92	0.94	0.91	0.74	0.89
1790	0.97	1.31	1.35	1.12	1.25	0.73	0.64	0.93	0.94	0.84
1800	1.08	1.07	1.15	1.51	1.36	1.37	1.16	1.17	0.89	0.94
1810	0.92	1.15	0.70	0.97	0.93	1.02	1.18	0.87	1.28	1.20
1820	0.90	1.09	0.65	0.64	0.63	1.02	1.24	0.98	1.28	0.94
1830	0.98	1.21	1.27	0.87	0.64	0.79	0.84	0.80	1.01	1.11
1840	1.22	0.62	0.88	0.67	0.61	0.90	0.54	0.49	0.54	0.67
1850	1.04	1.07	1.23	1.37	1.06	1.59	1.14	1.06	0.57	0.64
1860	1.03	0.95	0.79	1.02	0.52	0.81	1.05	0.97	1.25	1.43
1870	1.07	1.18	1.35	1.04	0.93	1.13	0.86	0.91	1.11	0.98
1880	0.66	0.97	0.91	1.02	1.07	1.79	1.42	1.04	1.07	0.80
1890	0.74	0.92	0.87	1.08	1.18	1.28	1.02	1.19	0.89	0.85
1900	1.04	0.89	0.90	1.16	0.94	0.88	1.01	1.16	1.09	1.32
1910	1.14	0.84	0.74	0.78	0.85	0.77	0.91	0.85	0.66	0.71
1920	0.73	0.72	0.69	0.88	0.56	....	....	....	....	....

Mount Wilson, California (W), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1720	....	....	....	....	....	10.40	11.00	9.10	9.10	5.90
1730	6.00	8.90	6.30	8.10	7.10	5.90	6.35	7.00	5.80	6.10
1740	6.70	7.90	7.75	6.60	5.85	8.95	7.05	8.45	7.60	8.90
1750	4.75	5.15	6.80	4.20	3.30	6.10	4.55	5.85	6.25	5.15
1760	6.30	7.60	5.85	7.30	9.35	5.85	8.70	7.25	8.55	6.61
1770	7.10	7.23	5.52	6.20	6.25	5.62	5.12	4.57	5.40	5.50

Mount Wilson, California (W), 8 trees—Continued

A.D.	0	1	2	3	4	5	6	7	8	9
1780	6.13	7.00	5.37	5.30	7.00	6.70	4.30	5.12	4.65	5.22
1790	5.32	4.90	6.45	5.97	4.45	2.88	2.77	4.60	3.77	5.47
1800	5.60	5.77	7.15	6.12	8.50	7.65	5.85	4.67	7.05	6.05
1810	5.75	6.15	4.56	4.72	4.42	5.49	5.34	4.81	6.86	5.40
1820	6.25	5.08	5.00	4.11	3.93	4.83	5.83	5.10	5.43	5.16
1830	4.86	4.63	5.98	4.26	3.85	4.41	4.00	4.96	4.91	5.26
1840	5.71	3.70	4.51	3.16	3.61	3.97	4.13	4.13	3.37	3.80
1850	4.55	4.45	4.70	5.06	4.99	6.50	2.79	2.81	3.46	4.82
1860	5.26	4.71	5.66	5.26	3.42	4.15	4.67	4.32	5.92	5.75
1870	6.21	5.01	5.46	5.49	5.12	5.70	4.86	4.01	4.93	4.42
1880	3.05	4.52	3.87	4.31	4.17	4.67	4.042	4.25	3.57	3.48
1890	4.89	5.11	4.62	4.63	4.18	4.27	3.85	3.60	3.96	2.77
1900	5.22	4.91	3.75	3.89	3.72	4.47	5.18	4.68	5.63	3.51
1910	3.38	3.17	3.93	3.85	3.91	4.25	4.45	4.81	3.76	4.47
1920	4.45	5.16	4.75	4.90	3.27	3.03	....	....	....	....

San Bernardino (SB), 6 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1810	....	....	....	....	....	....	....	....	....	1.88
1820	1.39	0.90	1.24	1.72	1.38	2.03	2.16	1.81	1.54	1.98
1830	1.74	1.54	1.51	1.50	1.02	1.41	1.36	1.19	1.17	1.25
1840	1.06	0.77	0.85	0.92	0.98	1.20	1.67	1.56	1.31	0.92
1850	1.10	1.27	1.30	1.88	1.22	1.67	1.08	0.94	1.15	1.14
1860	0.88	1.02	0.87	1.00	0.82	0.79	1.18	1.16	1.15	1.06
1870	1.06	1.23	1.66	1.60	1.77	1.66	1.22	1.09	1.17−	0.93
1880	0.65	0.93	0.73	0.89	0.77	1.03	0.75	0.65	0.73	0.86
1890	0.85 +	0.97	0.92	0.95	0.98	1.13	1.09	1.11	1.22	1.03
1900	1.42	1.41	1.07	0.91	1.03	0.76 +	0.88	0.89−	0.89	0.79
1910	0.74	0.71	0.88	0.92	1.03	0.76	1.07	0.86	0.80	0.83
1920	0.94	1.11	....	....	....	....	....	....	....	....

Charleston, Nevada (CH), 8 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1700	2.70	1.78	2.43	1.03	2.18	1.78	1.73	1.03	1.47	1.40
1710	0.95	1.13	1.22	0.82	1.12	1.07	0.61	0.83	1.00	1.08
1720	1.72	1.33	0.92	1.84	1.36	1.52	1.94	1.65	1.83	0.61
1730	1.54	1.26	1.44	1.41	1.38	1.12	0.63	1.00	1.51	1.05
1740	1.19	1.21	1.41	1.69	1.86	1.55	2.23	2.09	1.37	1.53
1750	2.00	1.54	1.23	0.77	0.72	0.73	0.99	1.09	1.37	1.73
1760	1.78	2.27	1.63	1.34	1.39	0.59	1.63	1.64	1.80	1.26
1770	1.39	1.55	1.77	1.35	2.28	1.82	1.90	1.27	1.09	1.19
1780	1.60	1.59	0.77	1.10	1.80	0.84	1.25	1.06	0.65	1.04
1790	1.02	1.14	1.59	2.10	1.66	0.36	0.64	1.15	0.97	1.52
1800	1.10	1.08	1.27	1.12	1.25	1.02	1.46	0.72	1.05	0.56
1810	0.69	1.09	1.20	0.51	0.82	0.79	1.06	1.06	2.13	2.43
1820	2.59	2.42	1.27	0.93	1.49	1.52	1.92	1.34	1.87	1.32
1830	1.57	1.58	1.88	1.55	1.42	1.43	0.65	1.66	1.57	1.90
1840	1.59	0.75	1.08	1.21	1.04	0.99	1.32	0.86	1.34	1.17
1850	1.29	1.04	1.42	1.76	1.84	1.70	0.78	0.26	0.79	0.88
1860	1.03	1.33	1.60	1.35	0.89	1.37	1.90	1.94	2.15	1.66
1870	2.18	1.76	1.38	1.66	2.08	2.11	1.88	1.59	1.67	0.95
1880	1.02	1.06	1.03	0.92	0.97	1.27	0.87	1.44	1.28	1.46
1890	1.49	1.78	1.86	1.86	2.11	1.72	1.13	1.54	1.24	0.53
1900	0.77	1.11	0.98	1.07	1.40	1.33	1.69	1.63	1.97	1.83
1910	1.62	1.53	1.55	1.59	1.67	1.37	1.63	1.61	2.20	1.74
1920	2.05	2.40	2.47	2.60	....	....	....	....	....	....

Pine Valley, California (PV), 4 trees

A.D.	0	1	2	3	4	5	6	7	8	9
1730	....	....	....	....	....	....	1.65	1.33	1.25	1.02
1740	1.33	1.11	0.67	1.34	1.29	0.87	0.71	0.43	0.53	0.25
1750	0.47	0.52	0.61	0.55	0.88	0.93	1.10	1.69	3.36	3.36
1760	4.20	3.67	2.86	2.30	2.32	1.40	3.44	3.60	3.50	2.56
1770	1.90	2.93	2.45	1.90	3.14	2.39	2.20	1.56	1.39	1.19
1780	1.06	1.49	0.58	1.40	2.19	1.52	2.75	2.82	1.84	1.65
1790	1.26	1.07	0.60	1.89	1.86	1.68	1.52	1.33	1.00	1.22
1800	1.25	1.46	2.16	1.90	1.50	1.97	1.29	1.21	1.67	1.16
1810	1.31	1.65	1.42	1.36	2.28	2.40	2.58	2.57	2.24	2.77
1820	0.95	1.30	0.85	0.55	0.62	1.10	1.46	1.16	2.10	0.64
1830	0.83	1.32	1.25	1.91	1.23	1.28	1.25	1.28	1.31	1.40
1840	1.25	0.81	1.39	0.55	0.65	0.51	0.99	0.85	1.18	1.15
1850	1.18	0.90	1.56	1.99	1.09	1.47	0.73	0.63	0.75	0.82
1860	0.95	1.09	1.39	1.22	0.88	1.27	1.23	0.92	1.41	1.48
1870	0.72	0.91	1.06	0.37	0.64	0.65	0.68	0.49	1.27	0.46
1880	1.19	1.16	0.61	0.59	0.90	1.20	1.27	1.29	2.04	1.63
1890	1.12	1.52	1.39	1.25	1.07	0.95	1.06	1.27	1.00	0.57
1900	0.67	0.84	0.53	0.41	0.21	0.64	0.64	0.59	0.72	0.89
1910	0.98	0.92	0.66	0.81	0.69	0.84	1.11	1.18	1.05	1.21
1920	1.38	0.93	1.28	....	....	....	....	....	....	....

BIBLIOGRAPHY

ABBOT, C. G. 1923. Solar radiation. Report of a conference on cycles. Sup. Geog. Rev., Vol. XIII, No. 4, October 1923: 669.

———. 1925. The earth and the stars.

———. 1925[2]. Solar variation and forecasting. Smith. Misc. Coll., vol. 77, No. 5, June 20, 1925.

———. 1925[3]. Discussion of analysis (of solar radiation). Bull. Am. Met. Soc., vol. 6, No. 7, July 1925: 99–100.

———. 1926. A new proof of the variability of the sun, based on Mount Wilson observations. Mon. Wea. Rev., vol. 54, No. 5, May 1926: 191–194.

———. 1927. A group of solar changes. Smith. Pub. 2916, April 25, 1927.

ADAMS, W. S. 1923. Sunspots and sunspot cycles. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 670–671.

ALLISON, VERNON C. 1923. The growth of stalagmites and stalactites. Jour. of Geology, vol. 31, No. 2, February-March 1923: 106–125.

ALTER, DINSMORE. 1921. An apparent rainfall period equal to one-ninth of the sunspot period. Mon. Wea. Rev., vol. 49, February 1921: 74–85.

———. 1922. Rainfall period equal to one-ninth the sunspot period. Kan. Univ. Sci. Bull., vol. 13, No. 2: 17–99. Abstract in Bull. Amer. Met. Soc., vol. 4, No. 3, March 1923: 37–38.

———. 1924. Application of Schuster's periodogram to long rainfall records beginning 1748. Mon. Wea. Rev., vol. 52, October 1924: 479–488.

———. 1926. Application of Schuster's periodogram to rainfall periods between $2\frac{1}{6}$ and 9 years. Bull. Amer. Met. Soc., vol. 7, No. 2, February 1926: 22–23.

———. 1926[2]. An examination by means of Schuster's periodogram of rainfall data from long records in typical sections of the world. Mon. Wea. Rev., vol. 54, February 1926: 44–57.

———. 1926[3]. Criteria of reality in the periodogram. Mon. Wea. Rev., vol. 54, February 1926: 57–58.

———. 1927. Investigation of rainfall periodicities between $1\frac{1}{6}$ and $2\frac{1}{2}$ years by use of Schuster's periodogram. Mon. Wea. Rev., vol. 56, February 1927: 60–66.

———. 1927[2]. A study of the possibility of economic value in statistical investigations of rainfall periodicities. Mon. Wea. Rev., vol. 55, March 1927: 110–112.

ÅNGSTRÖM, A. 1922. Solar constant, sunspots, and solar activity. Astroph. J., vol. 55, January 1922: 24–29.

ANTEVS, ERNST. 1922. Recession of the last ice sheet in New England. Am. Geog. Soc. Research series 11, 1922.

———. 1923. Cycles in glacial and postglacial deposits. Report of a conference on cycles. Geo. Rev., vol. 13, No. 4, Special Sup., October 1923: 664–665.

———. 1925. The climatologic significance of annual rings in fossil woods. Am. Jour. Sci., vol. 9, April 1925: 296–302.

———. 1925[2]. On the pleistocene history of the great basin. Quaternary climates, Carnegie Inst. Wash. Pub. 352: 51–114.

———. 1925[3]. The big tree as a climatic measure. Quaternary climates, Carnegie Inst. Wash. Pub. 352: 115–153.

———. 1925[4]. Retreat of the last ice-sheet in eastern Canada. Canada Dept. of Mines., Geol. Survey Memoir 146, No. 126, Geol. Series.

ARCTOWSKI, H. 1915. The pleionian cycle of climatic fluctuations. Proc. 2d Pan-Amer. Sci. Cong., Sec. II, vol. 2, 1917: 172. Same, 1916. Amer. Jour. Sci., vol. 42, July 1916: 27–33.

———. 1923. Dissimilitude des fluctuations de la fréquence des taches observées au N. et au S. de l'equateur solaire. Kosmos. (Bull. Soc. Pol. Nat.) Inst. Geophys. Univ. Léopol. Com. 2.

AUSTIN, L. W. 1927. Long-wave radio measurements at the Bureau of Standards in 1926, with some comparisons of solar activity and radio phenomena. Proc. Inst. Radio Eng., vol. 15, No. 10, 825–836, October 1927.

———. 1927[2]. Radio atmospheric disturbances and solar activity. Proc. Inst. Radio Eng., Vol. 15, No. 10, 837–842, October 1927.

BALLS, W. L. 1919. The existence of daily growth-rings in the cell-wall of cotton hairs. Proc. Roy. Soc. B, vol. 90, 1919: 542–555.

———. 1921. A simple apparatus for approximate harmonic analysis and for periodicity measurements. Proc. Roy. Soc. A, vol. 99, 1921: 283–292.

BALLS, W. L. 1922. Apparatus for determining the standard deviation mechanically. Proc. Roy. Soc. A, vol. 101, 1922: 333–341.

——— and H. A. HANCOCK. 1922². Further observations on cell-wall structure as seen in cotton hairs. Proc. Roy Soc. B, vol. 93, 1922: 426–440.

BATES, CARLOS G. and A. J. HENRY. 1921. Stream flow at Wagon Wheel Gap, Colorado. Mon. Wea. Rev., vol. 49, December 1921: 637–650.

——— and RAPHAEL ZON. 1922. Research methods in the study of forest environment. U. S. Dept. of Agr. Bull. No. 1059, May 19, 1922.

BAUER, FRANZ. 1922. Periodic oscillations of annual temperatures in Germany. Mon. Wea. Rev., vol. 50, April 1922: 199–200.

———. 1925. The 11-year period of temperature in the northern hemisphere in relation to the 11-year sunspot cycle. Mon. Wea. Rev., vol. 53, May 1925: 204–208.

———. 1925². The 3 to 3½ year periodic pressure oscillation in the free atmosphere. Mon. Wea. Rev., vol. 53, September 1925: 392–394.

BAUER, LOUIS A. 1923. Solar and terrestrial correlations. Discussion, report of a conference on cycles. Sup. Geog. Rev., Vol. XIII, No. 4, October 1923: 671–672.

———. 1926. Activity of the sun and of atmospheric electricity on land and sea, 1916–1920. Ter. Mag., vol. 31, March 1926: 31.

———. 1926². Sunspot and annual variations of atmospheric electricity with special reference to the Carnegie observations, 1915–1921. Carnegie Inst. Wash. Pub. 175 (vol. 5): 361–386.

——— and C. R. DUVALL. 1925–26. Studies concerning the relation between the activity of the sun and of the earth's magnetism, Nos. I and II. Ter. Mag., vol. 30, December 1925: 191–213, and vol. 31, March 1926: 37–47.

BAXTER, FRANK C. 1927. *See* COLTON, HAROLD S.

BEVERIDGE, W. H. 1921. Weather and harvest cycles. Economic Jour., December 1921: 429–452.

———. 1922. Wheat prices and rainfall in western Europe. Jour. Roy. Statistical Soc. (London), Vol. LXXXV, Part III, May 1922: 412–478.

BIGELOW, FRANK H. 1922. The vacuum-pyrheliometer and the solar radiation. Sup. No. 3 to treatises on atmospheres of sun and earth.

BJERKNESS, V., and colleagues. 1910–11. Dynamic meteorology and hydrography. Carnegie Inst. Wash. Pub. 88.

———. 1926. Solar hydrodynamics. Astroph. J., vol. 64, September 1926: 93–121.

BLAKE, DEAN. 1923. Sonora storms. Mon. Wea. Rev., vol. 51, No. 11, 1923: 585–588.

BLAKE, M. A. 1922. Peach yellows and little peach outbreaks come in cycles. New Jersey Agr., vol. 4, No. 4, April 1922: 1.

BOAK, A. E. R. 1926. Irrigation and population in the Faiyum, the Garden of Egypt. Geog. Rev., vol. 16, No. 3, July 1926: 353–364.

BROOKS, C. E. P. 1924. The difference periodogram—a method for the rapid determination of short periodicities. Proc. Roy. Soc. A, vol. 105, 1924.

———. 1926. Climate through the ages.

———. 1926². Sunspots and variations in the levels of the central African lakes. (A review.) Geog. Rev., vol. 16, No. 1, January 1926: 142–143. .

BROOKS, C. F. and FRANCES V. TRIPP. 1925. Solar radiation and the atmosphere. Bull. Am. Met. Soc., vol. 6, No. 2: 25.

———. 1926. A possible weather and ocean connection. Bull. Am. Met. Soc., vol. 7, No. 3, March 1926: 44.

BRYAN, KIRK. 1922. Erosion and sedimentation in the Papago country, Arizona, with a sketch of the geology. U. S. Geol. Survey Bull., No. 730 B. Contributions to the Geography of the United States, 1922: 19–90.

———. 1925. Date of channel trenching (arroyo cutting) in the arid southwest. Science, vol. 42, No. 1607, October 16, 1925: 338–344.

BURNS, GEORGE P. 1920. Eccentric growth and the formation of redwood in the main stem of conifers. Univ. of Vermont and State Agr. Coll. Vermont Agr. Exp. Sta. Bull. No. 219, June 1920.

BUSH, V. 1920. A simple harmonic analyzer. Jour. Am. Inst. Elect. Eng., October 1920: 903.

CAMPBELL, LEON. 1926. Maxima and minima of 272 long-period variable stars. Annals Ast. Obs. Harvard Coll., vol. 79, 1926: 91.

CANNON, W. A. 1925. Physiological features of roots, with especial reference to the relation of roots to the aeration of soil. Carnegie Inst. Wash. Pub. 368.

CARPENTER, FORD. A. 1924. Notes on the irregularities of ocean currents, Bull. So. Calif. Acad. Sci., vol. 20, No. 3, May–June 1924: 101–102.

CHANEY, RALPH W. 1925. A comparative study of the Bridge Creek flora and the modern redwood forest. Pub. 349, Carnegie Inst. Wash., 1925: 1–22.

CHANEY, RALPH W. 1925[2]. The Mascall flora—its distribution and climatic relation. Pub. 349, Carnegie Inst. Wash., 1925: 23–48.
CHIRVINSKY, P. N. 1923. Mechanism of sunspots. Astr. Nach. 5220, vol. 218: 178–186.
CHU, CO-CHING. 1926. Climatic pulsations during historic time in China. Geog. Rev., vol. 16, No. 2, April 1926: 274–284.
CLAYTON. H. H. 1917. Effect of short-period variations of solar radiation on the earth's atmosphere. Smith. Pub. 2446. May 1917.
———. 1920. Variation in solar radiation and the weather. Smith. Pub. 2544, January 15, 1920.
———. 1923. Variations in solar radiation and the weather. Abstract in Bull. Amer. Met. Soc., vol. 4, No. 3, March 1923: 33–34.
———. 1923[2]. The use of observations of solar phenomena in weather forecasting in Argentina. Abstract in Bull. Amer. Met. Soc., vol. 4, No. 3, March 1923: 34–37.
———. 1923[3]. World weather.
———. 1925. Solar radiation and weather, or forecasting weather from observations of the sun. Smith Misc. Coll., vol. 77, No. 6, June 20, 1925.
———. 1925[2]. Solar variation and the weather. Bull. Am. Met. Soc., vol. 6, No. 7, July 1925: 100–105.
———. 1925[3]. Solar variations (and discussion). Mon. Wea. Rev., vol. 53, December 1925: 522–528.
———. 1926. Solar activity and long-period weather changes. Smith. Inst. Pub. 2875, September 30, 1926.
CLEMENTS, F. E. 1920. Plant indicators: the relation of plant communities to processes and practice. Pub. 290, Carnegie Inst. Wash.
———. 1921. Drought periods and climatic cycles. Ecology, vol. 2, No. 3, July 1921: 181–188.
———. 1921[2]. Aeration and air content: the rôle of oxygen in root activity. Pub. 315, Carnegie Inst. Wash.
———. 1923. Nature of the problem of the cycle. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 657–659.
——— and J. E. WEAVER. 1924. Experimental vegetation: the relation of climaxes to climate. Pub. 355, Carnegie Inst. Wash.
CLOUGH, H. W. 1920. An approximate 7-year period in terrestrial weather with solar correlation. Mon. Wea. Rev., vol. 48: 593–597.
———. 1921. A statistical comparison of meteorological data with data of random occurrence. Mon. Wea. Rev., vol. 49, March 1921: 124–132.
———. 1924. A systematically varying period with an average length of 28 months in weather and solar phenomena. Mon. Wea. Rev., vol. 52, September 1924: 421–441.
———. 1925. A statistical analysis of solar radiation data. Mon. Wea. Rev., U. S. Dept. Agr., August 1925, vol. 53: 343–348. Abstract: Bull. Am. Met. Soc., July 1925: 97–98.
COLTON, HAROLD S. 1918. The geography of certain ruins near the San Francisco Mountains, Arizona. Bull. Geog. Soc. Philadelphia, vol. 16, No. 2, April 1918: 37–60.
——— and FRANK C. BAXTER. 1927. Days in the Painted Desert and the San Francisco Mountains.
CONZATTI, CASIANO. 1921. El arbol de Santa Maria del Tule, Secretaria de Educacion Publica de Mexico, Talleres Graficos de la Nacion: 1921.
CORTIE, Rev. A. L. 1923. Solar and terrestrial magnetic phenomena, 1913–1921. Mon. Not. Roy. Ast. Soc., vol. 83, No. 3, January 1923: 204–215.
DE GEER, GERARD. 1926. On the solar curve as dating the Ice Age, the New York moraine, and Niagara Falls through the Swedish time-scale. Data 9, Stockholms Högskolas Geokronol Inst. Geografiska Annaler, 1926, H. 4.
———. 1927. Late glacial clay varves in Argentina, measured by Dr. Carl Caldenius, dated and connected with the solar curve through the Swedish time-scale. Data 10, Fr. Stockholms Högskolas Geokronol Inst. Geografiska Annaler, 1927, H. 1–2.
DE LURY, R. E. 1922. Meteorological and astronomical pulses. Bull. Amer. Met. Soc., vol. 3, No. 3, March 1922: 38–39.
———. 1923. Arrival of birds in relation to sunspots. The Auk, vol. 40, No. 3, July 1923: 414–419.
———. 1925. Sunspots and the weather. Jour. Roy. Ast. Soc. Canada. December 1925: 293–298.
DE MIFFONIS, H. 1924. The periodoscope. Astroph. J., vol. 60, September 1924: 133–139.
DEADHAR, D. G. 1925. On atmospheric radio-activity and Indian weather. Proc. Roy. Soc., Series A, vol. 109, No. A750, October 1, 1925: 280–286.

DORNO, C. 1925. Fluctuations in the values of the solar constant. Mon. Wea. Rev., vol. 53, December 1925: 519–522.

DOUGLAS, A. W. 1919. Relation of weather and business in regard to rainfall. Chamber of Commerce, U. S. A., Special Bull., February 14, 1919.

———. 1919[2]. Relation of weather and business in regard to temperature. Chamber of Commerce, U. S. A., Special Bull., November 7, 1919.

DOUGLASS, A. E. 1919. Climatic cycles and tree-growth. Carnegie Inst. Wash. Pub. 289, Vol. I.

———. 1920. Evidence of climatic effects in the annual rings of trees. Ecology, vol. 1, No. 1, January 1920: 24–32.

———. 1921. Dating our prehistoric ruins. Nat. Hist. Amer. Mus., vol. 21, January 1921: 27.

———. 1921[2]. Indication of seasonal variation of weather in the growth of rings of trees. Jour. Elect. and West. Industry, vol. 46, May 15, 1921: 510.

———. 1922. Some topographic and climatic characters in the annual rings of the yellow pines and sequoias of the Southwest. Proc. Amer. Philo. Soc., Vol. LXI, No. 2, April 1922: 117.

———. 1922[2]. Some aspects of the use of the annual rings of trees in climatic study. Sci. Mon., Vol. 15: 5, July 1922. Reprinted, Smith. Report, 1922, Pub. 2731, 223–239.

———. 1923. Conclusions from tree-ring data. Report of a conference on cycles. Geog. Rev., Vol. 13, No. 4, Special Sup., October 1923: 659–661.

———. 1923[2]. General methods in the advance of cycle studies. Report of a conference on cycles. Sup. to Geog. Rev., Vol. XIII, No. 4, October 1923: 674.

———. 1925. Tree rings and climate. Radio talks on science. Sci. Mon., vol. 21, July 1925: 95–99.

———. 1925[2]. Notes on certain biologic cycles apparently related to solar activity. (Abstract.) Bull. Am. Met. Soc., August-September 1925: 129.

———. 1927. Solar records in tree growth. Science, Vol. LXV, No. 1679, March 4, 1927: 220–221.

DUVALL, C. R., and BAUER, LOUIS A. 1925–26. *See* BAUER.

EDDINGTON, A. S. 1926. The internal constitution of the stars. Cambridge University Press.

ELLSWORTH, R. S. 1924. The giant sequoia.

ELTON, C. S. 1924. Periodic fluctuations in the numbers of animals; their causes and effects. Br. Jour. Exp. Biol., Vol. II, October 1924: 119–163.

FREE, E. E. 1911. The movement of soil material by the wind. U. S. Dept. Agr., Bur. of Soils, Bull. No. 68.

GAIL, FLOYD W. 1921. Factors controlling the distribution of Douglas fir in semiarid regions of the northwest. Ecology, vol. 2, No. 4, October 1921: 281–291.

GALAIR, ANTONIO. 1916. Fluctuaciones climatologicas en los tiempos historicos. Proc. 2d Pan-Amer. Sci. Cong., Sec. 4, vol. 4, 1917: 475–481.

GRUNSKY, C. E. 1927. The improbability of rainfall cycles. Mon. Wea. Rev., vol. 55, February 1927: 66–69.

GUILD, F. N. 1920. Flagstaffite, a new mineral from Arizona. Amer. Mineralogist, vol. 5, No. 10, October 1920: 155–166.

———. 1921. The identity of Flagstaffite and terpin hydrate. Amer. Mineralogist, vol. 6, No. 9, September 1921.

HAASIS, FERDINAND W. 1921. Relation between soil type and root form of western yellow pine seedlings. Ecology, Vol. II, No. 4, October 1921: 292–303.

———. 1923. Significance of a 255–year age class in an eastern Kentucky forest. Jour. of Forestry, vol. 21, No. 7, November 1923.

HALE, G. E. 1924. Sunspots as magnets and the periodic reversal of their polarity. Nature, January 19, 1924.

———. 1925. A test of the electromagnetic theory of the hydrogen vortices surrounding sunspots. Proc. Nat. Acad. Sci., Vol. II, 1925: 691.

——— and S. B. NICHOLSON. 1925[2]. The law of sunspot polarity, Astroph. J., vol. 62, November 1925: 270–300.

———. 1926. Some new possibilities in solar research. Sup. to Nature. No. 2957, July 3, 1926.

———. 1926[2]. Observations with the spectrohelioscope. Nature, September 18, 1926.

———. 1926[3]. Visual observations of the solar atmosphere. Proc. Nat. Acad. Sci., vol. 12, 1926: 286.

———. 1927. The fields of force in the atmosphere of the sun. Nature, vol. 119, No. 3002, May 14, 1927.

HARRIS, J. A. 1926. The correlation between sunspot numbers and tree growth. Mon. Wea. Rev., vol. 54, January 1926: 13–14.

HELLAND-HANSEN, BJÖRN, and FRIDTJOF NANSEN. 1920. Temperature variations in the north Atlantic Ocean and in the atmosphere. Smith. Misc. Coll. 2537, vol. 70, No. 4, 1920.
HENRY, A. J. 1921. Temperature variations in the United States and elsewhere. Mon. Wea. Rev., vol. 49, February 1921: 62–70.
———. 1921². Seasonal forecasting of precipitation—Pacific coast. Mon. Wea. Rev., vol. 49, April 1921: 213–219.
——— and CARLOS G. BATES. 1921. Stream flow at Wagon Wheel Gap, Colorado. Mon. Wea. Rev., vol. 49, December 1921: 637–650.
———. 1922. Douglass on climatic cycles and tree growth. Mon. Wea. Rev., vol. 50, March 1922: 125–127.
———. 1922². Clements on drought periods and climatic cycles. Mon. Wea. Rev., vol. 50, March 1922: 127–131.
———. 1923. Terrestrial temperatures in the United States and the sunspot cycle. Mon. Wea. Rev., vol. 51, May 1923: 243–249.
———. 1926. The Brückner cycle in the United States. Mon. Wea. Rev., vol. 54, December 1926: 507.
HENRY, AUGUSTINE, and MARGARET G. FLOOD. 1920. The Douglas firs: a botanical and silvicultural description of the various species of *Pseudotsuga*. Proc. Roy. Irish Acad., vol. 35, Sec. B, No. 5, May 1920: 67–92.
HOFMANN, J. W. 1923. Meteorological factors and forest fires. (Abstract.) Bull. Am. Met. Soc., vol. 4, No. 12, December 1923: 166–169.
HOXMARK, GUILLERMO. 1925. Solar radiation and the weekly weather forecast of the Argentine Meteorological Service. Smith. Misc. Coll. 2827, vol. 77, No. 7, June 20, 1925.
HUMPHREYS, W. J. 1920. Physics of the air. Pub. Franklin Inst. of Penn.
———. 1925. Climatic control. Sci. Mon., Vol. XX: 449.
HUNTINGTON, ELLSWORTH. 1915. Solar activity, cyclonic storms, and climatic changes. Proc. 2d Pan-Amer. Sci. Cong., Sec. II, vol. 2, 1917: 411–432.
——— and S. S. VISHER. 1922. Climatic changes, their nature and causes. Yale Univ. Press.
———. 1923. Cycles of health. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 662–664.
———. 1923². Causes of cycles. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 667–669.
———. 1925. Tree growth and climatic interpretations. Quaternary climates. Carnegie Inst. Wash. Pub. 352, 155–204.
KAPTEYN, J. C. 1914. Tree growth and meteorological factors. Rec. Trav. Bot. Neerland, 11: 70, 1914.
KIDDER, A. V. 1924. An introduction to the study of southwestern archæology. Yale Univ. Press.
KIMBALL, H. H. 1919. Variation in the total and luminous solar radiation with geographical position in the United States. Mon. Wea. Rev., vol. 47, November 1919: 769–793.
——— and HERMAN E. HOBBS. 1923. A new form of thermo-electric recording pyrheliometer. Bull. Amer. Met. Soc., vol. 4, Nos. 6–7, June–July 1923: 91–92.
———. 1925. Smithsonian solar-constant values. Mon. Wea. Rev., U. S. Dept. of Agr., July 1925, No. 53: 303–306.
KNOWLTON, F. H. 1919. Evolution of geologic climates. Bull. Geol. Soc. Amer., vol. 30, December 31, 1919: 499–566.
LEMMON, J. G. 1900. Handbook of West-American cone-bearers.
LIVINGSTON, BURTON E., and FORREST SHREVE. 1921. Distribution of vegetation in the United States as related to climatic conditions. Carnegie Inst. Wash. Pub. 284.
LOCKYER, Sir NORMAN, and W. J. S. LOCKYER. 1904. The behavior of the short-period atmospheric-pressure variation over the earth's surface. Proc. Roy. Soc., vol. 73, April 13, 1904: 457–470.
LOSH, H. M. 1925. *See* NICHOLSON, S. B.
MACDOUGAL, D. T. 1921. Growth in trees. Pub. 307, Carnegie Inst. Wash., 1921.
———. 1923. Records of tree-growth. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 661–662.
——— and FORREST SHREVE. 1924. Growth in trees and massive organs of plants. Dendrographic measurements—MacDougal. The growth record in trees—Shreve. Pub. 350, Carnegie Inst. Wash., May 1924.
———. 1925. Reversible variations in volume, pressure and movements of sap in trees. Pub. 365, Carnegie Inst. Wash.
———. 1926. The hydrostatic system of trees. Pub. 373, Carnegie Inst. Wash.

MARVIN, C. F. 1920. Forecasting the weather on short-period solar variations. Mon. Wea. Rev., March 1920: 149–150.

———. 1921. Theory and use of the periodocrite. Mon. Wea. Rev., vol. 49, March 1921: 115–121.

———. 1923. Solar radiation intensities and terrestrial weather. Mon. Wea. Rev., vol. 51, April 1923: 186–188.

———. 1923². Periodicities in weather and climate. (Abstract.) Bull. Am. Met. Soc., vol. 4, No. 5, May 1923: 66–67.

———. 1923³. Concerning normals, secular trends, and climatic changes. Mon. Wea. Rev., vol. 51, August 1923: 383–390.

———. 1923⁴. Characteristics of cycles. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 666–667.

———. 1924. A new principle in the analysis of periodicities. Mon. Wea. Rev., vol. 52, February 1924: 85–89.

———. 1924². Fitting straight lines to data greatly simplified, with applications to sunspot epochs. Mon. Wea. Rev., vol. 52, February 1924: 89–91.

———. 1925. On the question of day-to-day fluctuations in the derived values of the solar constant. Mon. Wea. Rev., U. S. Dept. of Agr., July 1925, No. 53: 285–303.

———. 1925². Symposium: solar radiation and the weather. (Abstract.) Bull. Am. Met. Soc., vol. 6, No. 7, July 1925: 94–96.

———. 1925³. Solar radiation and weather forecasting. Report of Chief of Wea. Bur., U. S. Dept. of Agr., November 24, 1925.

———. 1926. The value of pyrheliometric readings alone for investigations on solar radiation and weather forecasting. Bull. Amer. Met. Soc., vol. 7, No. 2, February 1926: 21–22.

———. 1927. Measurements of solar radiation and their interpretation. Mon. Wea. Rev., vol. 55, February 1927: 49–56.

———. 1927². The Wolfer sunspot numbers analyzed as frequency distributions. Bull. Am. Met. Soc., vol. 8, No. 5, May 1927: 79.

MAUNDER, A. S. D. 1923. The sun and sunspots. Hutchinson's splendor of the heavens, ed. by Rev. T. E. R. Phillips and Dr. W. H. Steavenson: 110–153.

MAUNDER, E. WALTER. 1921–22. The prolonged sunspot minimum, 1645–1715. Jour. Br. Ast. Assoc., vol. 32, No. 4, 1921–22: 140.

———. 1922. The sun and sunspots, 1820–1920. Mon. Not. Roy. Ast. Soc., vol. 82, No. 9, Sup. No. 1, October 1922: 534–543.

McEWEN, GEORGE F. 1918. Oceanic circulation and its bearing upon attempts to make seasonal weather forecasts. Bull. Scripps Inst. Biol. Res., Univ. of Calif., No. 7, November 8, 1918.

———. 1922. Forecasting seasonal rainfall from ocean temperatures. Bull. Am. Met. Soc., vol. 3, No. 10, October 1922: 135.

———. 1923. How the Pacific Ocean affects Southern California's climate. Seasonal rainfall for 1923–24 indicated by ocean temperature. Bull. Am. Met. Soc., vol. 4, No. 10, October 1923: 142–148.

———. 1924. Forecasting seasonal rainfall from ocean temperatures. Indications for the 1924–25 season in Southern California. Bull. Am. Met. Soc., vol. 5, No. 10, October 1924: 137–139.

———. 1925. Ocean temperatures and seasonal rainfall in Southern California. Mon. Wea. Rev., vol. 53, November 1925: 483–489.

MEINZER, O. E. 1926. Plants as indicators of ground water. Jour. Wash. Acad. Sci., vol. 16, No. 21, December 18, 1926.

MILLER, DAYTON C. 1916. A 32-element harmonic synthesizer. Jour. Franklin Inst., January 1916: 53–81.

MILLER, ERIC R. 1920. Some characteristics of the Callendar pyrheliometer. Mon. Wea. Rev., June 1920, No. 48: 344–347.

MOORE, BARRINGTON. 1922. Influence of certain soil factors on the growth of tree seedlings and wheat. Ecology, vol. 3, No. 1, January 1922: 65–82.

MOORE, H. L. 1914. Economic cycles; their law and cause.

———. 1921. Generating cycles of products and prices. Quart. Jour. of Econ., vol. 35, February 1921: 215–239.

———. 1921². Generating cycles reflected in a century of prices. Quart. Jour. of Econ., vol. 35, August 1921: 503–526.

———. 1921³. The origin of the 8-year generating cycle. Quart. Jour. of Econ., vol. 36. November 1921: 1–29.

———. 1923. Economic cycles. Report of a conference on cycles. Geo. Rev., vol. 13, No. 4, Special Sup., October 1923: 662.

MORRIS, EARL H. 1919. The Aztec ruin. Anthropological papers of Amer. Mus. Nat. Hist., vol. 26, Part 1.

MURPHY, R. C. 1926. Oceanic and climatic phenomena along the west coast of South America during 1925. The question of periodicity. Geog. Rev., vol. 16, No. 1, January 1926: 53–54.

NELSON, N. C. 1921. Swiss lake-dweller discoveries. Nat. Hist., Vol. XXI, No. 2, 1921: 172–174.

NICHOLSON, S. B., and EDISON PETTIT. 1922. The application of vacuum thermo-couples to problems in astrophysics. Astroph. J., vol. 56, November 1922: 295–317.

——— and GEORGE E. HALE. 1925. The law of sunspot polarity. Astroph. J., vol. 62, November 1925: 270–300.

——— and H. M. LOSH. 1925². High and low maxima of alternate cycles. Contrib. Mt. Wilson Solar Obs. No. 300, Mon. Not., vol. 85, 1925: 467.

PEARSON, G. A. 1918. The relation between spring precipitation and height growth of western yellow pine saplings in Arizona. Jour. of Forestry, October 1918: 677–689.

———. 1923. Natural reproduction of western yellow pine in the Southwest. U. S. Dept. of Agr. Bull. No. 1105, April 27, 1923.

———. 1927. Grazing and reforestation. Jour. of Forestry, Vol. XXV, No. 5, May 1927.

PETTERSSON, O. 1923. Innere Bewegungen in den zwischenschichten des Meeres und der atmosphäre. Abstract in Geog. Rev., vol. 15, No. 4, October 1925: 690–691.

PETTIT, EDISON, and S. B. NICHOLSON, 1922. The application of vacuum thermo-couples to problems in astrophysics. Astroph. J., vol. 56, November 1922: 295–317.

———. 1926. Ultra-violet solar radiation and its variations. Pub. of Ast. Soc. of the Pacific, vol. 38, February 1926: 21–27.

———. 1926². Ultra-violet solar radiation and atmospheric ozone. Pop. Ast., vol. 34, December 1926: 631.

———. 1927. Ultra-violet solar radiation. Proc. Nat. Acad. Sci., vol. 13, June 1927: 380–387.

PICKARD, GREENLEAF W. 1927. The correlation of radio reception, solar activity, and terrestrial magnetism. Proc. Inst. Radio Eng., vol. 15, No. 2, 83–97, February 1927, and vol. 15, No. 9, 749–766, September 1927.

PICKERING, W. H. 1920. The relation of telescopic definition to cold waves. Mon. Wea. Rev., September 1920, No. 48: 511.

———. 1920². The relation of prolonged tropical droughts to sunspots. Mon. Wea. Rev., 1920, No. 48: 589–592.

ROBBINS, WILLIAM J. 1921. Precipitation and the growth of oaks at Columbia, Missouri. Univ. of Missouri, Coll. of Agr., Agr. Exp. Sta. Research Bull. No. 44.

ROWE, EDGAR A. 1925. The value of long-range rainfall forecasting to irrigation and water-supply projects in Southern California from an engineering standpoint. (Abstract.) Bull. Amer. Met. Soc., vol. 6, No. 12, December 1925: 180.

SANFORD, F. 1926. Comparison of earth-potential and air-potential variations. Bull. Terr. Elec. Obs. of Fernando Sanford, vol. 3, July 1926: 14–20.

———. 1927. Summary of observations on earth-potential and air-potential gradients for the year 1926, with some theoretical considerations. Bull. Terr. Elec. Obs., March 1927.

SAYLES, ROBERT W. 1922. The dilemma of the palæoclimatologists. Amer. Jour. of Sci., vol. 3, June 1922: 456–473.

SCHOTTE, GUNNAR. 1922. Summary of the programme of the Swedish State Institute of Experimental Forestry for the period 1922–1926. (In Swedish, German, and English). Meddelanden Fran Statens Skogsförsökssanstalt, Häfte 19, No. 1.

SHREVE, FORREST. 1914. The rôle of winter temperatures in determining the distribution of plants. Amer. Jour. of Bot., vol. 1, No. 4, April 1914: 194–202.

———. 1914². Rainfall as a determinant of soil moisture. Plant World, vol. 17, No. 1, January 1914: 9–26.

———. 1917. A map of the vegetation of the United States. Geog. Rev., vol. 3, No. 2, February 1917: 119–125.

———. 1917². The physical control of vegetation in rain-forest and desert mountains. Plant World, vol. 20, No. 5, May 1917: 135–141.

———. 1917³. The density of stand and rate of growth of Arizona yellow pine as influenced by climatic conditions (*Pinus chihuahuana* and *arizonica*). Jour. of Forestry, vol. 15, No. 6, October 1917: 695–707.

———. 1919. A comparison of the vegetational features of two desert mountain ranges. Plant World, vol. 22, No. 10, October 1919: 291–307.

———. and BURTON E. LIVINGSTON. 1921. Distribution of vegetation in the United States as related to climatic conditions. Pub. 284, Carnegie Inst. Wash.

———. 1922. Conditions indirectly affecting vertical distribution on desert mountains. Ecology, vol. 3, No. 4, October 1922: 269–274.

SHREVE, FORREST. 1924. Soil temperature as influenced by altitude and slope exposure. Ecology, vol. 5, No. 2, April 1924: 128–136.

SONDEREGGER, A. L. 1924. Cyclic fluctuations of water-supply. Pacific Engineer, vol. 2, No. 6, October 1924: 6–16.

———. 1925. A discussion of the water problems of the valley of Southern California. Modern Irrigation, vol. 1, No. 1, July 1925: 18, 34–35.

SPOEHR, H. A. 1922. Photosynthesis and the possible use of solar energy. Jour. Indus. and Engin. Chem., vol. 14, No. 12, December 1922: 1142.

STENZ, EDWARD. 1925. Sur la théorie de l'actinometre et sur les mésures de la radiation solaire dans les montagnes. Kosmos, T. 50, 1925: 462–479. Reprint, Inst. Géophys. Univ. Léopol. Com., 13.

STRATTON, F. J. M. 1924. Astronomical physics. Chap. IV, The sun, 25: 53–55.

STREIFF, A. 1926. On the investigation of cycles and the relation of the Brückner and solar cycle. Mon. Wea. Rev., vol. 54, July 1926: 289–296.

———. 1927. Sunspots and rainfall. Mon. Wea. Rev., vol. 55, February 1927: 69–72.

SWINDELLS, Rev. B. G. 1923. Comparison of sunspot areas and terrestrial magnetic horizontal force ranges 1911–21. Mon. Not. Roy. Ast. Soc., vol. 83, No. 3, January 1923: 215–217.

TCHIJEWSKY, A. L. 1924. Physical factors of the historical process.

TINGLEY, F. G. 1923. A proposed system of graphical extrapolation of weather data, with possible application to long-range forecasting. (Abstract.) Bull. Am. Met. Soc., vol. 4, No. 5, May 1923: 69–70.

TRIPP, FRANCES V. 1925. Solar climate. Bull. Am. Met. Soc., vol. 6, No. 2, February 1925: 30.

——— and C. F. BROOKS. 1925². Solar radiation and the atmosphere. Bull. Am. Met. Soc., vol. 6, No. 2: 25.

TURNER, H. H. 1919. On the 15-month periodicity in earthquake phenomena. Mon. Not. Roy. Ast. Soc., vol. 79, No. 6, April 1919: 461.

———. 1919². On a long period (about 240 years) in Chinese earthquake records. Mon. Not. Roy. Ast. Soc., vol. 79, No. 7, May 1919: 531.

———. 1920. The long-period terms in the growth of trees. Mon. Not. Roy. Ast. Soc., Vol. LXXX, No. 9, Sup. No., October 1920: 793–808.

———. 1920². Note on the 240-year period in Chinese earthquakes in the light of Dr. Fotheringham's paper. Mon. Not. Roy. Ast. Soc., Vol. LXXX, No. 6, April 1920: 617–620.

———. 1925. Note on the alteration of the 11-year solar cycle. Mon. Not. Roy. Ast. Soc., vol. 85, No. 5, March 1925: 467.

———. 1926. On a period of approximately 9.2 years in the Greenwich observations of magnetic declination and horizontal force. Mon. Not. Roy. Ast. Soc., vol. 86, No. 3, January 1926: 108–118.

———. 1926². On an unsuccessful search for the 9.2-year magnetic period in sunspot records, with a new analysis of those records back to 1610. Mon. Not. Roy. Ast. Soc., vol. 86, No. 3, January 1926: 119–130.

VAUGHAN, T. WAYLAND. 1923. Sediments and climate. Report of a conference on cycles. Geog. Rev., vol. 13, No. 4, Special Sup., October 1923: 665.

VERY, FRANK W. 1913. A criterion of accuracy in measurements of atmospheric transmission of solar radiation. Astroph. J., vol. 37, No. 1, January 1913: 31–47.

VISHER, S. S., and ELLSWORTH HUNTINGTON. 1922. Climatic changes, their nature and causes. Yale Univ. Press.

———. 1925. The solar-cyclonic hypothesis and the glacial periods. Sci. Mon., Vol. XX, 1925: 475.

WEAVER, J. E., and F. E. CLEMENTS. 1924. Experimental vegetation: the relation of climaxes to climate. Pub. 355, Carnegie Inst. Wash.

WEST, FRANK L. 1920. Long-time temperature prediction. Science, n. s., vol. 52, No. 1356, December 24, 1926: 611–612.

WOLFER, A. 1915. Tafeln der sonnenfleckenhaüfigkeit für die Tätig-keitsperiode von 1901 bis 1914. Meteorologischen Zeitschrift, Heft 5, 1915: 193–195.

———. 1918 etc. Astromische Mitteilungen Nr. CVII to CXIV gegründet von Dr. Rudolf Wolf. 1918–1926.

———. 1921. Die sonnenfleckenhaüfigkeit in den Jahren 1902–1920. Jubilaümsnummer der Astr. Nachr.

———. 1925. Observed sunspot relative numbers, 1749–1924. Terr. Mag. and Atmos. Elec., Vol. XXX, No. 2, June, 1925: 83–86.

WOOLARD, E. W. 1925. On the mean variability in random series. Mon. Wea. Rev., vol. 53, 107–112, 1925.

WYLIE, CHARLES C. 1927. The solar cycle in temperature and in crops. Pop. Ast., vol. 35, No. 5, May 1927: 253–256.

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